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STEP
Strategies for Today's
Environmental Partnership

Evaluation of Fuel Tank Flammability of Low RVP Gasolines

Health and Environmental Sciences Department
Publication Number 4646
December 1996

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Strategies for Today's
Environmental Partnership

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API PUBLICATION NUMBER 4646

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ABSTRACT

The changes in fuel properties brought on by the reformulation of gasoline to reduce VOC emissions in urban areas with severe ozone problems have raised concerns about potential impacts on the flammability of hydrocarbon vapors in closed storage vessels such as automobile fuel tanks. A desire to define the effects of reformulated gasoline (RFG) on flammability temperature limits prompted this study. Several experiments were performed to evaluate the conditions under which the vapors from reformulated gasoline (RFG) contained in automobile fuel tanks become flammable. The program was conducted with 22 test fuels that had been systematically varied with respect to Reid vapor pressure (RVP), pentane-to-butane ratio, and addition of ethanol and MTBE. In Phase I, vapor pressures were measured for each test fuel over a 15 to 130°F temperature range. In addition, the upper and lower temperature limits of flammability were measured for each fuel. Phase II involved measurements of the concentrations of hydrocarbons in the vapor phase and an assessment of stratification.

The results show that temperature limits of flammability correlate with RVP. The upper flammability temperature limits increase as RVP is reduced. The addition of either MTBE or ethanol or both to gasoline indicates a moderate increase in upper flammability limits. Gasoline blends containing ethanol, including those commingled with MTBE, elevate the upper flammability limits more substantially than do gasoline blends containing MTBE. The lower temperature limits of flammability also increase as RVP is reduced, although less markedly than the upper limits.

The flammable concentration limits of the gasolines containing ethanol are substantially greater than those containing MTBE or no oxygenates. The flammable concentration limits of gasolines containing MTBE are only slightly higher than those of the test gasolines with no oxygenates. The ratio of C_5-to-C_4 hydrocarbons in the fuel has no consistent effect on either the upper temperature limits of flammability or the upper concentration limits of flammability when comparing fuels at similar RVP levels.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

Section Page

Appendix A

Appendix B

Appendix C

Appendix D

Appendix E

Appendix F

Appendix G

Appendix H

LIST OF ILLUSTRATIONS

LIST OF TABLES

GLOSSARY OF TERMS

Lower Concentration Limit of Flammability (LCLF) - The lowest concentration of vapor in dry air which will propagate a flame away from an ignition source. (The lean flammability limit of the fuel vapor.)

Upper Concentration Limit of Flammability (UCLF) - The highest concentration of vapor in dry air which will propagate a flame away from an ignition source. (The rich flammability limit of the fuel vapor.)

Lower Temperature Limit of Flammability (LTLF) - Temperature at which the lower concentration limit of flammability (LCLF) exists in dry air under conditions of vapor-liquid equilibrium. Temperatures below the LTLF result in gasoline vapor concentrations that are too low to propagate a flame away from an ignition source.

Upper Temperature Limit of Flammability (UTLF) - Temperature at which the upper concentration limit of flammability (UCLF) exists in dry air under conditions of vapor-liquid equilibrium. Temperatures above the UTLF result in gasoline vapor concentrations that are too high to propagate a flame away from an ignition source.

EXECUTIVE SUMMARY

The changes in fuel properties brought on by the reformulation of gasoline to reduce emissions in urban areas with severe ozone problems have raised concerns about potential impacts on the flammability of hydrocarbon vapors in closed storage vessels such as automobile fuel tanks. Recent changes to gasoline which are needed to meet the federal requirements for reformulated gasoline (RFG) include the addition of ethanol and/or methyl *t*-butyl ether (MTBE), reduction in the benzene content, and lower Reid vapor pressure (RVP). The primary means for lowering RVP is to reduce the amount of butane in the gasoline. Lowering the RVP results in a decrease in the concentration of hydrocarbon vapors in the vapor space above the fuel. For gasoline, this decrease would tend to raise the upper temperature limit of flammability (UTLF). Oxygenates also could increase the upper temperature limit of flammability of fuel vapors as these compounds generally have wider flammability limits than hydrocarbons. At temperatures below the upper temperature limit of flammability, the concentration of vapors in a fuel tank can fall to the point where there is sufficient air or oxygen to sustain combustion or an explosion if an adequate ignition source is present.

In 1995, the American Petroleum Institute (API) sponsored a study to define the effects of reformulated gasoline (RFG) on flammability temperature limits. The study was conducted on 22 test fuels that had been systematically varied with respect to RVP, pentane-to-butane ratio, and concentrations of ethanol and MTBE. In Phase I, vapor pressures of each of these test fuels were measured over temperatures ranging from 15 to 130°F. Correlations were developed to predict vapor pressures as functions of temperature for the various fuels. Upper and lower temperature limits of flammability were determined and correlated with vapor pressure and differences in composition.

Phase II involved measurements of the concentrations of hydrocarbons in the vapor phase at the upper temperature limit of flammability (UTLF) of each test fuel and correlation of these results with the predicted upper concentration limits of flammability reported in Phase I. Phase II also entailed an assessment of stratification in an automobile fuel tank. Experiments were performed to study the interaction of temperature change, air dilution and mass diffusion rate with respect to changes in vapor-liquid equilibrium in fuel tanks.

The reader should be aware that this study is not an assessment of the "risk" of igniting vapors from low RVP and oxygenated fuels in a fuel tank. Such an assessment would have required both a detailed technical analysis of potential sources of ignition and the determination of the probabilities of igniting flammable fuel tank vapors by the various sources. That type of analysis was beyond the scope and level of resources available for this effort.

The following key findings result from the experiments conducted in this study:

- The temperature limits of flammability correlate with RVP. The upper flammability temperature limits increase as RVP is reduced. The temperature limits for non-oxygenated fuels correlate well with prior studies. The addition of either MTBE or ethanol or both to gasoline yields a moderate increase in upper flammability limits. Gasoline blends containing ethanol, including those commingled with MTBE, elevate the upper temperature limits of flammability to a greater extent than gasoline blends containing MTBE alone. The lower temperature limits of flammability also increase as RVP is reduced, although less markedly than the upper limits.

- The Clausius-Clapeyron relationship accurately defines vapor pressure as a function of the temperature and Reid vapor pressure for each of the test gasoline and gasoline/oxygenate blends.

- A generalized expression for the dependence of vapor pressure on absolute temperature and RVP can be established for each fuel group, i.e., neat gasoline, gasoline/MTBE blends, etc.

- The upper concentration limits of flammability (UCLF) of the gasolines containing ethanol are markedly greater than those containing MTBE or no oxygenates. The UCLF of gasolines containing MTBE are only slightly higher than the limits of the test gasolines containing no oxygenates.

- The ratio of C_5-to-C_4 hydrocarbons in the fuel has no consistent effect on the measured values of either the upper temperature limits of flammability or the upper concentration limits of flammability when comparing fuels at similar RVP levels.

- Stratification of vapors in fuel tanks results from changes in temperature which cause air to enter (or be ingested by) the tank. Deviations of vapor concentrations from equilibrium conditions in a fuel tank are explainable in terms of air ingestion resulting from temperature change and mass transport effects on the re-establishment of equilibrium. At constant temperature, up to 4 hours are required to reach vapor-liquid equilibrium in a closed storage vessel.

- A decrease in temperature causes air to enter and dilute the fuel vapors in a fuel tank. The effect of air dilution on fuel tank vapor concentration is somewhat offset by lags between changes in ambient temperature and fuel temperature which can be as much as 3 hours. When the ambient temperature falls, the reduction in fuel temperature lags behind and this causes the concentration of vapors in the tank to remain higher than the equilibrium concentration for the ambient temperature.

- The air dilution and molecular diffusion associated with a 24-hour diurnal cycle over an 84 to 60 °F ambient temperature range has a relatively small effect on the departure of vapor concentrations in a fuel tank from equilibrium conditions. The vapor concentration does not fall more than 20% below equilibrium levels. The effects of these two phenomena (air dilution and molecular diffusion) on the dynamics of vapor-liquid equilibrium concentrations in a fuel tank are only important (with respect to reaching the UCLF) when there are rapid changes in ambient temperature.

Section 1
INTRODUCTION

Most accidents involving fire are caused by fuel tank rupture. Spilled gasoline is the worst of fire hazards because its vapors can be ignited and can quickly envelop the vehicle. Other fire hazards involve fuel leaks in the engine compartment where the hot exhaust manifold and corona discharge around ignition wires are potential ignition sources. On the other hand, very few, if any, fire-related accidents in automobiles have been attributed to explosions within the fuel tank. Therefore, fuel tank flammability is a safety concern that has not been extensively studied.

One reason that there has been limited investigation of fuel tank vapor flammability is that the vapors in a fuel tank are often not flammable. At temperatures above a certain level, the concentration of gasoline vapors relative to air in the vapor space of an automotive fuel tank is well in excess of the point where the mixture would become flammable (i.e., the rich or upper flammability limit) if exposed to an ignition source.(1) Conversely, when the fuel temperature falls below a certain level, the concentration of air relative to fuel vapors in the tank prevents ignition from occurring (i.e., the lean or lower flammability limit). Consequently, between these two temperature limits, the vapors are flammable and could be ignited if subjected to a sufficiently intense ignition source. Temperatures that define the flammable range of the fuel vapor are termed the upper and lower temperature limits of flammability. Temperature limits of flammability are affected by Reid vapor pressure (RVP) and fuel composition.

Congress, through the Clean Air Act Amendments of 1990, required that a cleaner burning gasoline be used in the nine cities in the United States with the worst urban ozone levels in 1995. Specifications were set to define a "Reformulated Gasoline" (RFG) to reduce the exhaust and evaporative emissions of ozone-forming compounds and air toxics, such as benzene. Table 1-1 compares the properties of conventional gasoline versus RFG produced to meet EPA's performance requirements using the EPA "Simple

Model." Most of the changes to meet the specifications under the "Simple Model" are accomplished by adding ethanol and/or methyl *t*-butyl ether (MTBE) and by lowering the butane content. The change with the greatest impact on fuel tank flammability, however, is reduced RVP. Reduced vapor pressure decreases evaporative emissions but hinders cold startability and elevates the upper temperature limit of flammability.

Table 1-1. Fuel Parameters for Conventional Gasoline and "Simple Model" RFG

Fuel Property	Conventional Gasoline		Simple Model RFG
	Average*	Range†	
RVP,‡ psia	8.7(S) 11.5(W)	6.9-10.1(S) 9.9-15.1(W)	7.2/8.1(S) 11.5(W)
T50, °F	207	178-251(S) 166-239(W)	n/a
T90, °F	332	307-369(S) 286-357(W)	≤ 1990 Refinery Baseline Avg
Aromatics, vol%	28.6	6.1-52.2(S) 6.6-47.2(W)	Controlled as Necessary to Meet the Toxics Emissions Performance Std.
Olefins, vol%	10.8	0.4-26.0(S) 0.4-29.9(W)	≤ 1990 Refinery Baseline Avg
Benzene, vol%	1.60	0.1-3.89(S) 0.1-5.18(W)	≤0.95 Avg (1.3 max)
Sulfur, ppm	338	10-1100(S) 10-1170(W)	≤ 1990 Refinery Baseline Avg
Oxygen from Oxygenates, Wt %	---	0.04-2.4(S) 0.04-2.5(W)	1.5 Min >2.1 Avg 2.7(S)/3.5(W) Max

*As defined in the Clean Air Act
†1990 Summer and Winter MVMA surveys (gasohol excluded)
‡Winter (W) higher than Summer (S) to maintain vehicle performance

The primary means for lowering RVP is to reduce the amount of butane in the gasoline. Decreasing the RVP results in an increase in the air-fuel ratio and this tends to raise the upper temperature limit of flammability. Oxygenates also could increase the upper temperature limit of flammability as they generally have wider flammability limits than hydrocarbons. The introduction of RFG, therefore, has the potential of affecting flammability limits, and increases in the upper temperature limit of flammability raise the potential risk of a fuel tank explosion. A desire by the American Petroleum Institute (API) to define the effects of RFG on flammability temperature limits prompted this study.

In the present study, Southwest Research Institute (SwRI) was contracted by API to evaluate the effects of RVP and fuel composition on the flammability of RFG vapors in fuel tanks. The study was conducted on 22 test fuels that had been systematically varied with respect to RVP, pentane-to-butane ratio, and concentrations of ethanol and MTBE. In Phase I, vapor pressures of each of these test fuels were measured over temperatures ranging from 15 to 130°F. Correlations were developed to calculate vapor pressures as functions of temperature for the various fuels. Upper and lower temperature limits of flammability were determined and correlated with vapor pressure and differences in composition.

Phase II involved measurements of the concentrations of hydrocarbons in the vapor phase at the upper temperature limit of flammability (UTLF) of each test fuel and correlation of these results with the UTLF measurements reported in Phase I. Phase II also entailed an assessment of stratification in an automobile fuel tank. Experiments were performed to determine the effects of temperature change and mass diffusion on the time needed to attain a fuel vapor-liquid equilibrium in fuel tanks.

The term "RVP" is used in this document for convenience at times to truly mean Reid vapor pressure and at other times to mean "Dry Vapor Pressure Equivalent" (DVPE). The DVPE values were obtained using a Grabner vapor pressure meter and employing the American Society for Testing and Materials (ASTM) test method D 5191.(13) This procedure reports a correlated DVPE which is equivalent to that provided from ASTM D 4953(13), the standard test method for measuring the vapor pressure of gasoline and gasoline-oxygenate blends. As ASTM D 4953 is, itself, a modification of the traditional ASTM D 323(14) test method for measuring Reid vapor pressure, DVPE can be considered a surrogate for RVP.

Section 2

TEST FUELS

FUELS PROCUREMENT AND FORMULATION

Three reformulated baseline gasolines (FL2221, FL2222, and FL2223) were procured from Phillips Petroleum Company (PPC). The PPC fuels met the basic specifications of Phase I reformulated gasoline described in Table 1-1. However, the gas chromatographic analysis revealed higher than desired levels of C_4 hydrocarbons, cyclopentane, cyclohexane, and n-heptane. Since the hydrocarbon composition of the PPC fuels was somewhat atypical of reformulated gasolines, the fuel matrix was complemented with two additional baseline fuels (FL2407 and FL2408) that were formulated to provide vapor pressures similar to the PPC fuels FL2223 and FL2221 but with a more typical distribution of species and minimal amounts of butane. One of these new fuels (FL2408) was further modified late in the program by adding C_5/C_6 isomerate to create two additional gasolines (FL2409 and FL2410) that served to extend the RVP range of the baseline gasoline fuel set.

The new fuels were blended according to the formulations shown in Table 2-1. All of the fuel components were typical gasoline blendstocks except for the de-butanized alkylate and the hydrotreated Fluidized Catalytic Cracked (FCC) heavy gasoline. The reformate (95 RON platformate) was obtained from PPC, while the "FCC Heavy" and "FCC Light Naphtha" gasolines were obtained through API. The hydrotreated FCC heavy gasoline was made by hydrotreating the gasoline in the SwRI Alternative Fuels Center. The alkylate was provided by Coastal States Petroleum Company in Corpus Christi, Texas, and was de-butanized because it contained about 5 percent butane in its original state. The de-butanization was performed by cooling the alkylate to 45°F and purging with nitrogen. Lowering the temperature favored the relative volatilization of the lighter hydrocarbons. The C_5/C_6 isomerate was procured from Southwestern Refining Company.

Table 2-1. Composition of Baseline Gasolines Prepared at SwRI

Fuel Component	RVP, psia	Specific Gravity	Baseline Gasoline ID (RVP, psia)			
			FL2407 (5.37) wt% (vol%)	FL2408 (7.29) wt% (vol%)	FL2409 (7.89) wt% (vol%)	FL2410 (8.94) wt% (vol%)
Reformate	1.8	0.7980	25.00 (26.68)	24.00 (25.94)	22.82 (20.80)	20.42 (18.33)
FCC Heavy	1.7	0.7775	6.00 (6.24)	5.00 (5.27)	4.76 (4.45)	4.26 (3.93)
SwRI FCC Heavy Hydrotreated	1.6	0.8163	16.00 (17.47)	15.00 (16.59)	14.27 (12.71)	12.77 (11.21)
De-Butanized Alkylate	3.1	0.7062	30.00 (28.33)	22.00 (21.05)	20.92 (21.54)	18.72 (18.99)
FCC Light Naphtha	9.2	0.7119	17.00 (16.18)	18.00 (17.36)	17.11 (17.49)	15.32 (15.42)
C_5/C_6 Isomerate	16.7	0.6360	6.00 (5.10)	16.00 (13.79)	20.12 (23.01)	28.51 (32.12)

FUEL ANALYSIS

Fuel speciation was performed with a Hewlett-Packard model 5890 gas chromatograph equipped with a 105-m capillary column and a flame ionization detector. Data acquisition was performed with Chrom Perfect software designed specifically for speciation and PIANO analysis of complex hydrocarbon mixtures. The 105-m capillary column was obtained from Restek Corporation, and calibration standards consisting of 167 hydrocarbons were obtained from Supelco, Inc. Chromatograms on several off-the-shelf compounds were run and added to the hydrocarbon data base. Fluorescence Indicator Analysis (FIA) was used to measure the volume fractions of saturates, olefins, and aromatics in the baseline gasolines. Table 2-2 presents fuel properties and composition, while Table 2-3 shows the ASTM D 86 boiling point distributions of the baseline gasolines. Fuels FL2409 and FL2410 are absent from Tables 2-2 and 2-3. As noted previously, these two fuels were included late in the program and consequently were not measured for most of the properties shown in Tables 2-2 and 2-3.

Table 2-2. Baseline Gasoline Properties and Compositions

Baseline Gasoline (Source) / Fuel Property	FL2223 (PPC)	FL2222 (PPC)	FL2221 (PPC)	FL2407 (SwRI)	FL2408 (SwRI)
Specific Gravity	0.7523	0.7500	0.7460	0.7447	0.7339
Dry Vapor Pressure Equivalent (DVPE), psia	5.40	6.35	7.15	5.37	7.29
C_4 Hydrocarbons, wt%	1.58	2.43	3.08	0.38	0.52
C_5 Hydrocarbons, wt%	8.99	8.28	9.82	11.09	19.13
C_6 Hydrocarbons, wt%	22.20	20.66	21.79	8.61	13.35
C_7 Hydrocarbons, wt%	20.69	19.59	19.90	14.52	17.73
C_8 Hydrocarbons, wt%	29.15	26.62	26.09	31.25	29.83
C_{9+} Hydrocarbons, wt%	17.39	22.42	19.32	34.15	19.44
Benzene, wt%	1.13	1.05	1.11	0.82	0.95
Toluene, wt%	7.48	7.03	7.17	7.78	7.92
Butane, wt%	1.58	2.42	3.08	0.38	0.45
n-Pentane, wt%	0.96	0.90	1.06	2.08	5.30
iso-Pentane, wt%	2.63	2.42	3.15	6.04	9.05
Cyclopentane, wt%	3.42	3.15	3.50	0.27	0.69
Cyclohexane, wt%	8.77	8.11	8.47	0.10	0.10
iso-Octane, wt%	9.97	7.34	7.54	10.39	9.65
n-Heptane, wt%	4.15	3.87	3.97	0.80	0.88
Saturates, vol%*	70.3	67.1	69.4	68.8	70.1
Aromatics, vol%*	22.4	24.7	23.3	24.7	22.9
Olefins, vol%*	7.3	8.2	7.3	6.3	7.0

* Analysis by FIA method

Table 2-3. ASTM D 86 Boiling Point Distributions of Baseline Gasolines, °F

Base Fuel % Evaporated	FL2223	FL2222	FL2221	FL2407	FL2408
IBP*	109	104	96	103	95
5	145	130	125	132	115
10	159	149	144	149	129
20	177	173	167	175	146
30	190	189	185	197	165
40	203	204	199	215	189
50	216	217	214	231	214
60	228	234	229	244	235
70	250	253	250	263	254
80	281	279	278	293	282
90	330	321	325	334	326
95	370	366	351	363	359
EP†	409	409	407	415	415

* IBP = Initial boiling point
† EP = End point

Fuels FL2223 and FL2407 had DVPEs of ≈ 5.3 psia, and fuels FL2221 and FL2408 had DVPEs of ≈ 7.2 psia. However, the light-end compositions of both pairs of test gasolines were very different. These differences between the fuels of similar RVP are reflected both in the hydrocarbon analyses and in the boiling point distributions. By design, the ratio of C_5-to-C_4 hydrocarbons was much higher in the SwRI fuels (FL2407 and FL2408) than in the PPC fuels (FL2221, FL2222 and FL2223). Because of these differences in C_5-to-C_4 ratios, iso-pentane should be the predominate species in the vapor phase of fuels FL2407, FL2408, FL2409, and FL2410, while butane should dominate the vapor phase of fuels FL2221, FL2222, and FL2223.

It can be seen in Table 2-2 that the PPC fuel set contains substantially more C_6 and C_7 hydrocarbons than does the SwRI fuel set, particularly with the 5.4 psi RVP fuels. The high concentrations of C_{6-7} hydrocarbons (and lower concentrations of C_5 hydrocarbons) in the PPC fuels compensate for the abnormally high level of butane in these gasolines.

FUEL MATRIX

Table 2-4 describes the 7 baseline gasoline and 15 oxygenated gasoline test fuels examined in the study. The 15 oxygenated gasoline blends were made by splash blending ethanol, MTBE, and an ethanol/MTBE mix into each of 5 of the baseline gasolines (FL2221, FL2222, FL2223, FL2407 and FL2408). Five fuels were produced by splash blending 10 vol% ethanol into each of these 5 baseline gasolines. (These fuels are labeled with the code "FLnnnnA". where the "A" indicates ethanol and the "nnnn" refers to the numerical designation of the corresponding base fuel.) Five more fuels were produced by splash blending 15 vol% MTBE into each of the 5 aforementioned baseline gasolines. (The MTBE fuels are identified with the code "B" using the convention described above.) The last 5 fuels were made by commingling equal portions of the 10 percent ethanol and 15 percent MTBE blends. (The commingled oxygenated fuels are coded with the letter "C.") The other 2 baseline gasolines (FL2409 and FL2410) were not blended with any oxygenate. These 2 fuels were included only for the purpose of extending the vapor pressure range of the baseline gasolines.

Table 2-4. Test Fuel Descriptions

Code Name	Description	Blending Site	DVPE, psia
FL2221	Baseline Gasoline	PPC	7.15
FL2221A	FL2221 + 10 vol% Ethanol	SwRI	8.10
FL2221B	FL2221 + 15 vol% MTBE	SwRI	7.51
FL2221C	50 vol% FL2221A + 50 vol% FL2221B	SwRI	8.13
FL2222	Baseline Gasoline	PPC	6.35
FL2222A	FL2222 + 10 vol% Ethanol	SwRI	7.44
FL2222B	FL2222 + 15 vol% MTBE	SwRI	6.94
FL2222C	50 vol% FL2222A + 50 vol% FL2222B	SwRI	7.51
FL2223	Baseline Gasoline	PPC	5.40
FL2223A	FL2223 + 10 vol% Ethanol	SwRI	6.58
FL2223B	FL2223 + 15 vol% MTBE	SwRI	6.19
FL2223C	50 vol% FL2223A + 50 vol% FL2223B	SwRI	6.68
FL2407	Baseline Gasoline	SwRI	5.37
FL2407A	FL2407 + 10 vol% Ethanol	SwRI	6.55
FL2407B	FL2407 + 15 vol% MTBE	SwRI	6.07
FL2407C	50 vol% FL2407A + 50 vol% FL2407B	SwRI	6.72
FL2408	Baseline Gasoline	SwRI	7.29
FL2408A	FL2408 + 10 vol% Ethanol	SwRI	8.33
FL2408B	FL2408 + 15 vol% MTBE	SwRI	7.71
FL2408C	50 vol% FL2408A + 50 vol% FL2408B	SwRI	8.24
FL2409	Baseline Gasoline	SwRI	7.89
FL2410	Baseline Gasoline	SwRI	8.94

Section 3
PHASE I STUDY

This section presents the vapor pressure measurements that were performed during Phase I of the study. The procedures and results of the experiment to quantify temperature limits of flammability also are detailed.

VAPOR PRESSURE MEASUREMENTS

Apparatus and Procedure

Vapor pressures were measured with a Grabner model CCA-VPS and a Grabner model CCA-VP equipped with Peltier cooler. The model CCA-VPS was used to measure vapor pressures in the 70 to 130°F range, while the model CCA-VP was used to measure vapor pressures in the 15 to 70°F range. For the latter, a separate fluid cooling apparatus was used to assist the Peltier cooler in reaching temperatures below 30°F. The instruments were calibrated with 2,2-dimethyl butane and n-pentane standards. Also, data on neat ethanol were compared with literature data.(2) Vapor pressures of neat ethanol, neat MTBE, and the 22 test fuels were measured at 14 temperatures in the 15 to 130°F range. Several measurements were made at low temperatures (15 to 30°F) or in the region of the upper temperature limits of flammability of the test fuels.

Results

The vapor pressure data are given in Tables A-1 through A-4 in Appendix A. Figure 3-1 shows Clausius-Clapeyron plots(3) of the neat ethanol and neat MTBE data. The measured vapor pressures for ethanol are in good agreement with the literature data(2) in the figure. The slope of the curve for ethanol is steeper than that for MTBE because ethanol has a significantly higher heat of vaporization. Figures A-1 through A-4 in Appendix A show Clausius-Clapeyron plots of the vapor pressures of the 22 gasoline and gasoline/oxygenate test fuels. It can be seen in Figure A-1 and Table A-1 that the baseline gasolines with similar RVPs, i.e., fuels FL2223 and FL2407 and fuels FL2221 and FL2408, have similar vapor pressures throughout the temperature range of 15 to

130°F. The same behavior is also noted for the oxygenated gasoline blends containing ethanol, MTBE, and a mixture of ethanol/MTBE, i.e., blends with similar RVPs have similar vapor pressures throughout the temperature range.

The fuel blends containing ethanol and MTBE have higher vapor pressures than the baseline gasolines. MTBE is expected to increase the RVP because its vapor pressure is higher than the vapor pressures of the gasolines that were blended with MTBE. The addition of ethanol to the base gasoline caused the Reid vapor pressures of the resulting blends to increase by 1.0 to 1.2 psi even though the RVP of ethanol is substantially less than the RVPs of the base gasolines. The RVP of neat ethanol is lower than its molecular weight would suggest because of hydrogen bonding between the molecules. When ethanol is dissolved in gasoline, the hydrogen bonding is disrupted and its effective vapor pressure is increased and is more representative of its low molecular weight.

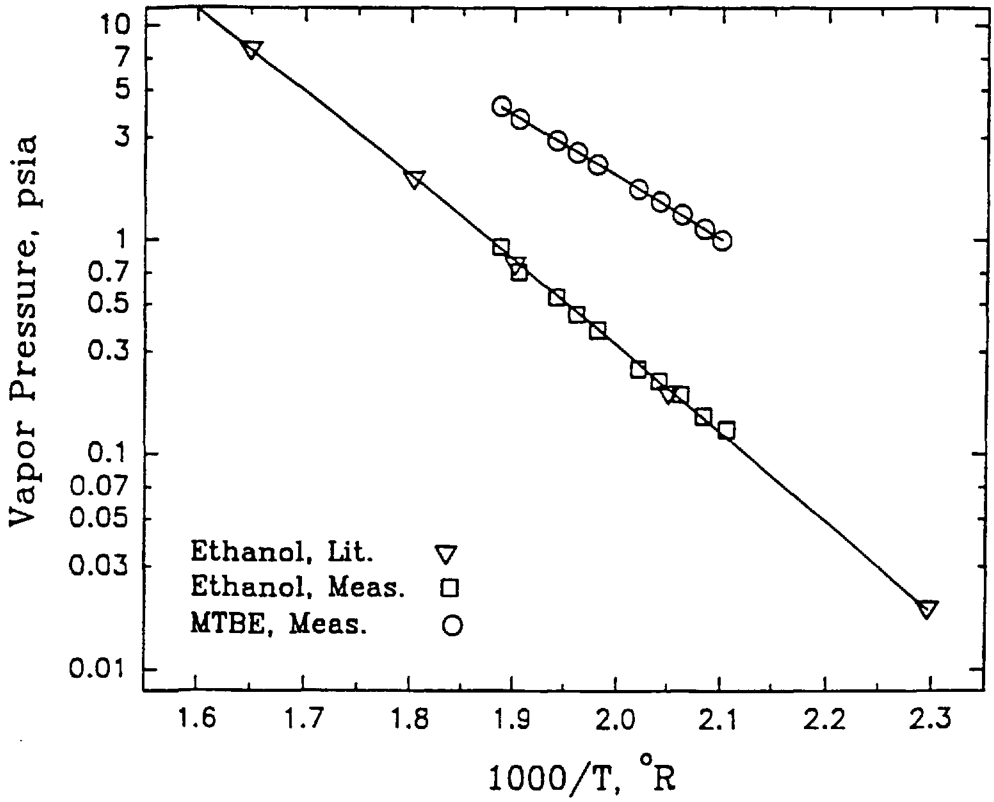

Figure 3-1. Clausius-Clapeyron plots for ethanol and MTBE showing the effect of temperature on vapor pressure

The vapor pressure data for each test fuel were correlated according to the expression

$$\mathrm{Log}_{10}(P_{\mathrm{vap}}) = A + \frac{B}{T} + \frac{C}{T^2} \qquad \text{(Eq. 1)}$$

where P_{vap} is the vapor pressure in psia; T is the absolute temperature in °R; and A, B, and C are correlation coefficients. Table 3-1 gives the correlation coefficients determined for each test fuel, including neat ethanol and MTBE.

Table 3-1. Coefficients for the Expression $\mathrm{Log}_{10}(P_{vap}) = A + B/T + C/T^2$ Where P_{vap} is in psia and T is in °R

Fuel Name	*A*	*B*	*C*
FL2221	3.587	-631.1	-505,880.3
FL2222	4.017	-1,104.4	-392,592.2
FL2223	5.413	-2,671.0	-25,410.7
FL2407	4.590	-1,790.9	-208,978.8
FL2408	3.217	-167.7	-644,537.1
FL2409	3.982	-1,015.9	-396,474.8
FL2410	4.182	-1,200.4	-337,870.2
FL2221A	4.451	-1,273.3	-398,073.7
FL2222A	4.632	-1,462.9	-360,397.4
FL2223A	4.602	-1,452.3	-372,749.4
FL2407A	5.545	-2,542.1	-57,570.1
FL2408A	5.124	-2,049.1	-168,498.8
FL2221B	2.936	184.0	-750,699.9
FL2222B	2.659	509.8	-857,787.1
FL2223B	2.367	815.8	-952,611.6
FL2407B	3.781	-799.3	-494,002.2
FL2408B	2.521	665.4	-884,767.6
FL2221C	4.252	-1,090.5	-437,482.8
FL2222C	4.129	-950.6	-488,333.1
FL2223C	4.748	-1,644.1	-309,436.0
FL2407C	5.134	-2,124.8	-159,498.2
FL2408C	4.793	-1,723.1	-248,833.3
MTBE	3.303	-106.6	-697,785.0
Ethanol	6.294	-2,745.6	-326,283.0

Because all the gasoline test fuels exhibited similar vapor pressure behavior (see Figures A-1 through A-4), it was feasible to create a generalized expression for the dependence of vapor pressure on absolute temperature and RVP. A nonlinear regression analysis of the data in Tables A-1 through A-4 was correlated according to the expression

$$P = RVP \exp\left(a + \frac{b}{T} + \frac{c}{T^2}\right) \qquad \text{(Eq. 2)}$$

where *P* is the vapor pressure in psia; *RVP* is the Reid vapor pressure in psia; *T* is the absolute temperature in °R; and *a*, *b*, and *c* are constants.

Equations 1 and 2 are based on the Clausius-Clapeyron equation which may be expressed as

$$Ln(P_{vap}) = \frac{\Delta H_{vap}}{RT} + C \qquad \text{(Eq. 3)}$$

where P_{vap} is the vapor pressure in psia; ΔH_{vap} is the heat of vaporization; *R* is the ideal gas constant; *T* is the absolute temperature in °R; and *C* is a constant. Equation 3 indicates that $Ln(P_{vap})$ is inversely proportional to the absolute temperature. This relationship would hold completely true if the heat of vaporization were constant. In fact, there is a slight variation of ΔH_{vap} with temperature, which is the reason for the C/T^2 term in Equation 1.

The correlation was performed on all of the test fuels as a group and subsequently on each of the four fuel classes, i.e., base fuels, ethanol blends, MTBE blends and ethanol/MTBE commingled blends. Table 3-2 gives values of the empirical constants *a*, *b*, and *c* for each of the fuel groups.

Table 3-2. Correlation Coefficients for the Expression $P = RVP \exp(a + b/T + c/T^2)$, Where P is in psia, RVP is Reid Vapor Pressure in psia, and T is in °R

Fuel Group	Data	*a*	*b*	*c*
All 22 Test Fuels	296	6.540	-1419.8	-1.257×10^6
Base Fuels	101	6.229	-1384.7	-1.178×10^6
10% Ethanol Blends	65	9.044	-3877.3	-6.629×10^5
15% MTBE Blends	65	3.754	1578.0	-2.063×10^6
Ethanol/MTBE Commingled Blends	65	8.490	-3352.3	-7.837×10^5

Figure 3-2 shows excellent agreement between the vapor pressures predicted using the overall correlation and all of the measured values for the 22 gasoline test fuels that had

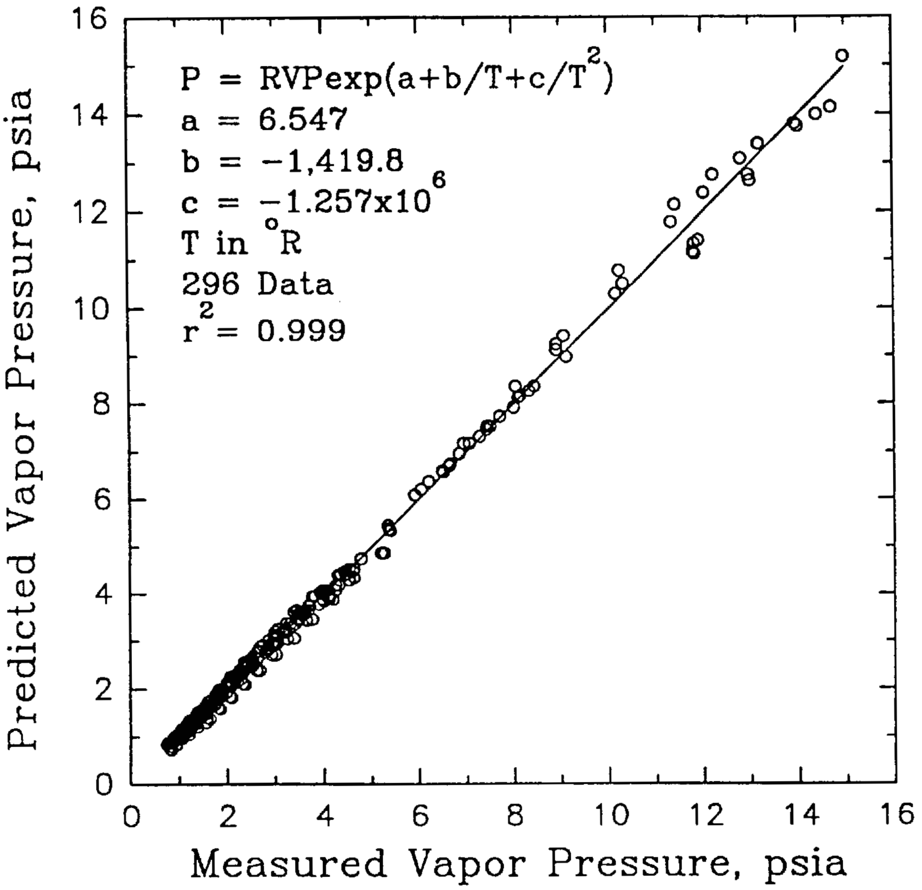

Figure 3-2. Comparison of vapor pressures predicted by Eq. 2 with measured values

been determined over the range of 15°F to 130°F. The accuracy of the correlation is exhibited in Appendix B where the numerical values of the measured and predicted vapor pressures are compared in terms of residual differences between measured and predicted. While the correlation based on all of the test fuels gave very small residuals, the residuals obtained from correlations of the individual fuel groups were even smaller. The results of the correlations shown in Table 3-2 indicate that there are slight differences in heat of vaporization among the fuel groups. The fuel groups containing ethanol had higher values of the constant *b*, indicating that their heats of vaporization were higher than those of the other fuel groups. However, the absolute differences in predicted vapor pressures of baseline gasolines and gasolines containing ethanol of the same RVP were less than 0.2 psia.

TEMPERATURE LIMITS OF FLAMMABILITY

Apparatus

The apparatus used in this study was similar to that used by Fanick *et al.*(4) and Lawson *et al.*(5) to measure flammability limits of fuel vapors. The combustion vessel shown in Figure 3-3 was a 500-mL three-neck round bottom pyrex flask. The flask dimensions were sufficient to preclude wall quenching effects on the flammability limits.(6, 7) The electrodes for ignition and the thermocouples for measuring fuel temperature were mounted in rubber stoppers that were placed in ports of the round bottom flask. The ignitor electrodes consisted of two 10-cm lengths of 14-gauge copper wire mounted parallel in the stopper 12.7 mm apart. The copper electrodes were sharpened to a point and bent at the ends to form a 2.5-mm spark-gap at the center of the flask. The electrodes were insulated with a polyethylene sheath up to where they were bent to form the spark-gap. An automotive spark coil capable of producing a continuous 400-Hz oscillating arc discharge was used to ignite the fuel vapors. Each ignition pulse was about 70 mJ, so at a rate of 400 Hz, the source delivered ≈ 280 mJ in 0.01 seconds.[a]

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[a] Typically, ignition coils for gasoline engines store from 60 to 120 mJ.(8) This energy is delivered each time the spark plug fires.

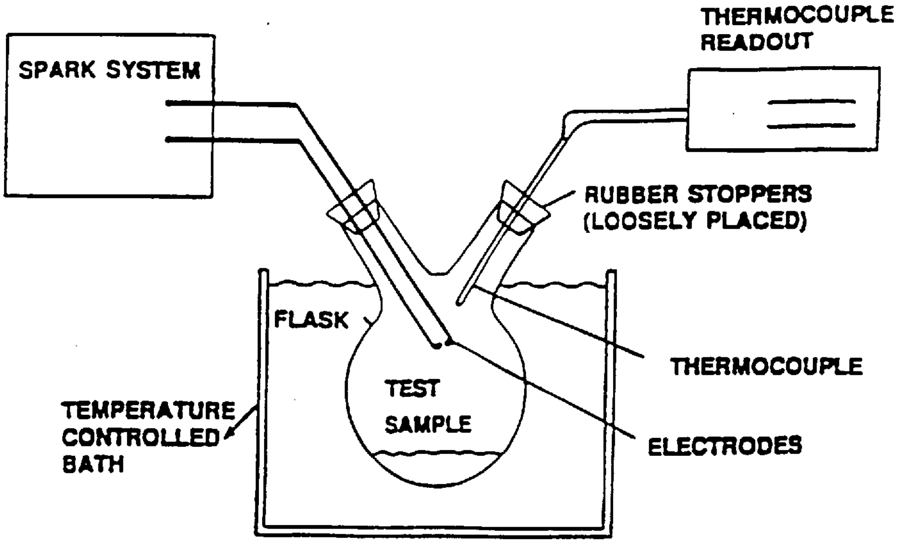

Figure 3-3. Temperature limit of flammability test apparatus

The source was left on for at least 2 seconds in each ignition test.

Aside from an open flame, an electric spark is the most effective means of ignition. A spark energy of approximately 0.2 mJ is sufficient to ignite a stoichiometric hydrocarbon-air mixture. Rich and lean mixtures require over 3 mJ.(8) Therefore, a continuously firing automotive spark coil ignitor, such as that used in the present study, would be considered an overwhelming ignition source.

Procedure

The combustion vessel was filled with 25 mL of test fuel. It was agitated in order to wet the walls of the flask so the fuel would evaporate and mix with the air. The flask was immersed in a constant temperature isopropanol/water bath controlled to within 0.5°C. It required about 30 minutes for the liquid fuel and bath temperatures to equilibrate. An attempt was made to ignite the fuel-air mixture about 20 minutes after the liquid fuel and bath temperatures equilibrated. The temperature limits of flammability were determined by a trial and error process.

At the start of testing, a target bath temperature was chosen. If ignition occurred at the chosen temperature, it would be characterized as weak, medium, or strong, depending on the aural intensity of the explosion. If the explosion was weak, the conditions were very close to the temperature limit of flammability. Therefore, in the next test the bath temperature would be raised just a few degrees. If no ignition occurred, the temperature limit was within a few degrees of the bath temperature in the last test. Once the temperature limit of flammability was bracketed to within a few degrees, tests were performed in 1°C increments to achieve accuracy to within 1°C.[b]

Results

The temperature limits of flammability were derived by interpolation of the test data given in Table C-1 of Appendix C. The test results and interpolations are accurate to within ≈ 2°F. Table 3-3 gives temperature limits of flammability in units of °F and corresponding vapor phase concentration limits for each of the test fuels. The concentration limits in Table 3-3 were calculated for each fuel using Eq. 1 and the constants *A*, *B*, and *C* in Table 3-1. The upper and lower concentration limits calculated in Table 3-3 are assumed to be equivalent to the respective upper and lower flammability limits that are normally reported in the literature.

The literature values for the upper and lower flammability limits of ethanol are 18.95 and 3.28 mole percent, respectively.⁽²⁾ Table 3-3 shows upper and lower flammability limits of ethanol observed in this experiment as 12.4 and 3.64 mole percent (mole %), respectively. The lean flammability limits agree with each other reasonably well, but the

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[b] Hereafter, the data on temperature limits of flammability will be reported and discussed in terms of degrees Fahrenheit in order to facilitate comparisons with other studies.

Table 3-3. Limits of Flammability

Fuel Name	RVP, psia	Temperature Limits		Concentration Limits*	
		Upper, °F	Lower, °F	Upper Mole %	Lower Mole %
Ethanol	2.41	91.4	53.6	12.40	3.64
MTBE	8.34	18.5	-14.8	7.48	2.42
Cyclohexane	3.36	49.1	5.7	6.02†	1.46†
FL2221	7.15	15.8	-41.8	7.37	1.06
FL2222	6.35	17.6	-31.0	6.68	1.41
FL2223	5.40	19.4	-23.8	6.22	1.84
FL2407	5.37	19.4	-25.6	6.12	1.59
FL2408	7.29	12.2	-34.6	6.50	1.27
FL2409	7.89	8.8	N‡	7.11	N
FL2410	8.94	2.3	N	7.02	N
FL2221A	8.10	12.2	-32.8	6.47	1.35
FL2222A	7.44	14.0	-38.2	6.07	0.95
FL2223A	6.58	21.2	-22.0	6.54	1.53
FL2407A	6.55	23.0	-25.6	7.54	1.69
FL2408A	8.33	12.2	-29.2	7.43	2.00
FL2221B	7.51	14.0	-32.8	6.67	1.24
FL2222B	6.94	15.8	-32.8	6.07	0.99
FL2223B	6.19	19.4	-22.0	5.83	1.28
FL2407B	6.07	24.8	-31.0	7.45	1.19
FL2408B	7.71	10.4	-31.0	6.01	1.28
FL2221C	8.13	6.8	-31.0	5.62	1.50
FL2222C	7.51	17.6	-29.2	6.91	1.36
FL2223C	6.68	21.2	-25.6	6.86	1.46
FL2407C	6.72	23.0	-25.6	7.81	1.73
FL2408C	8.24	10.4	-31.0	7.03	1.84

* Concentration limits calculated using vapor pressure correlations in Table 3-1.
† Concentration limits calculated using literature vapor pressure data.(2)
‡ No data

rich limit cited in the literature(2) is 53 percent too high. Most of the flammability limits in the literature were determined at the Bureau of Mines by evidence of visible flame propagation when mixtures were ignited in glass tubes.(6, 7, 10) Cool flame chemiluminescence is sometimes mistaken for ignition. Chemiluminescence has the appearance of flame propagation, but it occurs without any measurable rise in pressure or temperature. Cool flames occur predominantly in fuel rich mixtures, so they often complicate the definition of the upper flammability limit.

More recent work in a constant volume combustion bomb(11) showed that the upper flammability limits of the low molecular weight alcohols are substantially lower than accepted values. This was because ignition was detected by pressure rise instead of visible flame radiation. The upper flammability limit determined for ethanol by the combustion bomb method was 14.3 mole percent, which agrees more closely with the value of 12.4 mole percent in Table 3-3.

The flammability limits of MTBE are not well documented, but when compared with butane and pentane (see Appendix D), the values in Table 3-3 seem reasonable. The upper and lower flammability limits of cyclohexane (7.75 and 1.26 mole percent,(2) respectively) agree reasonably well with the concentration limits in Table 3-3. In general, the concentration limits in Table 3-3 are narrower than the flammability limits determined at the Bureau of Mines.(6, 7, 10)

As mentioned above, this difference most probably results from differences between the methods used to measure flammability limits, but it may also have something to do with temperature. Most flammability limits available in the literature were measured at temperatures greater than ambient. The concentration limits in Table 3-3 were determined at temperatures well below ambient. Since flammability limits widen with increased temperature, they are expected to be narrower at lower temperatures. Temperature may play a role in explaining why the upper concentration limits of ethanol, cyclohexane, and the test fuels in Table 3-3 are slightly lower than the literature values.

In Table 3-3, the upper concentration limits of the 22 test baseline gasolines and gasoline/oxygenate blends range from 5.62 to 7.81 mole percent, and lower limits range from 0.95 to 2.00 mole percent. The upper concentration limits are similar to those determined by Marshall and Schoonveld(12) for gasolines of varying RVP. Marshall and Schoonveld sampled the vapor space in a fuel tank by pumping the gasoline-air mixture into Tedlar bags. An ignition device was used to ignite the mixture in the Tedlar bags. The mixtures seldom ignited when the vapor concentration exceeded 8 mole percent and almost always ignited when the vapor concentration was less than 6 mole percent.

Literature values for flammability limits of several hydrocarbons are given in Appendix D. Literature values in parentheses in Table D-1 seem more realistic because they were determined from evidence of pressure rise in a constant volume combustion apparatus instead of from flame luminescence. Without knowledge of the exact composition of the test fuel vapors, the upper concentration limits in Table 3-3 appear to be slightly lower than the C_4 to C_8 hydrocarbons in Appendix D. However, the comparison would probably be more favorable if it were made with literature values measured at the appropriate temperature and by evidence of pressure rise rather than flame luminescence.

Figure 3-4 shows the relationship between the temperature limits of flammability and RVP for all fuels tested. Fuels with high RVP tend to have lower temperature limits of flammability. The curve shown in the plot is based on estimates made by Marshall and Schoonveld.(12) The temperature limits of the 22 baseline gasoline and gasoline/oxygenate blend test fuels compare favorably with the upper temperature limit estimates of Marshall and Schoonveld.(12) Figure 3-5 shows the effect of RVP on the upper temperature limits of the 22 test fuels, classified by oxygenate blend component. The open symbols represent the high C_4, PPC-based fuels; the filled symbols represent the high C_5 fuels blended at SwRI.

The trend lines in Figure 3-5 are least squares fits. (The coefficients for these least squares regressions are provided in Appendix E.) The figure shows that the upper temperature limits of flammability of the base/MTBE blends are on average only 1.3°F higher than the upper temperature limits of the baseline gasolines over the range of 6.5

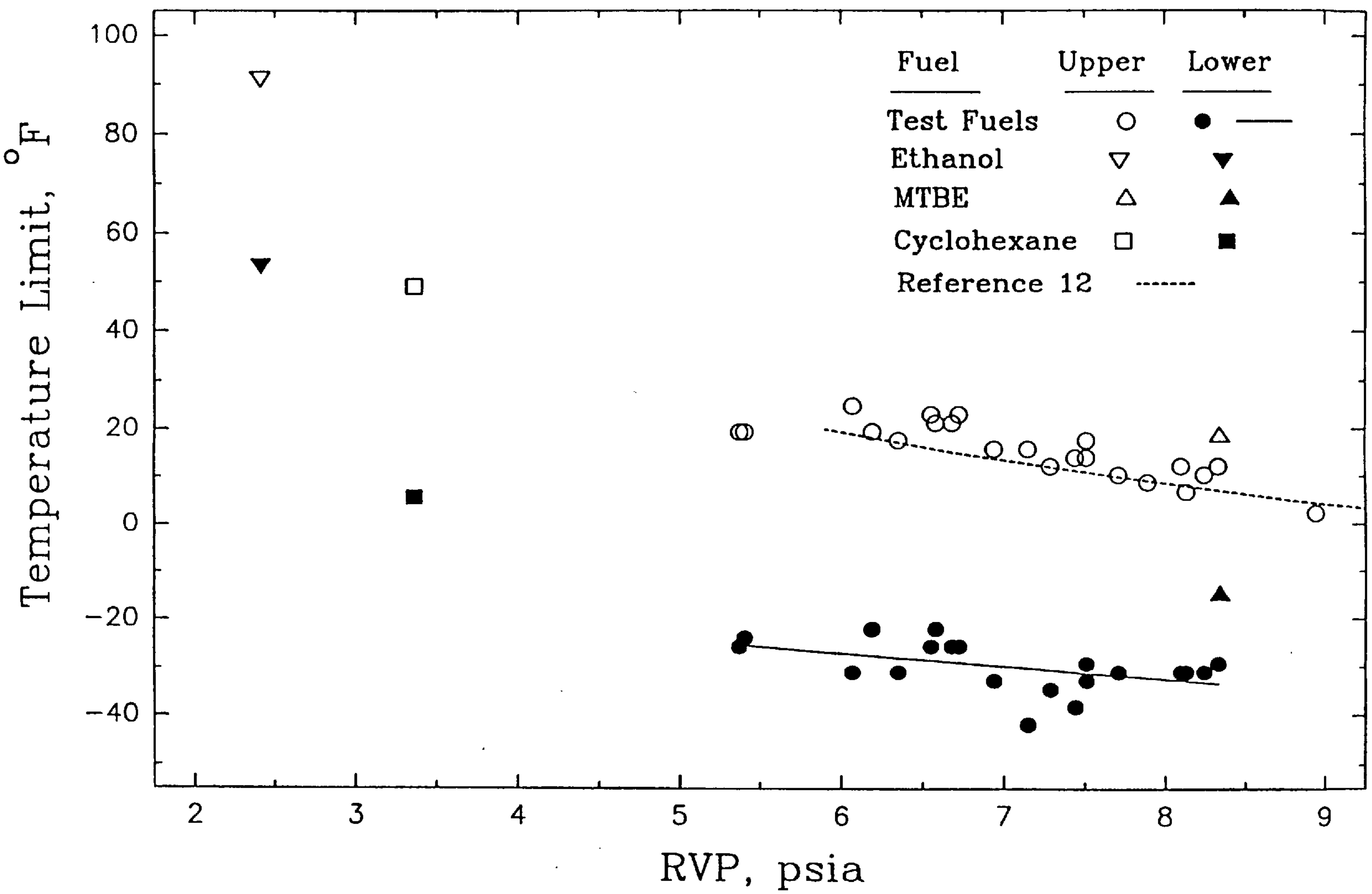
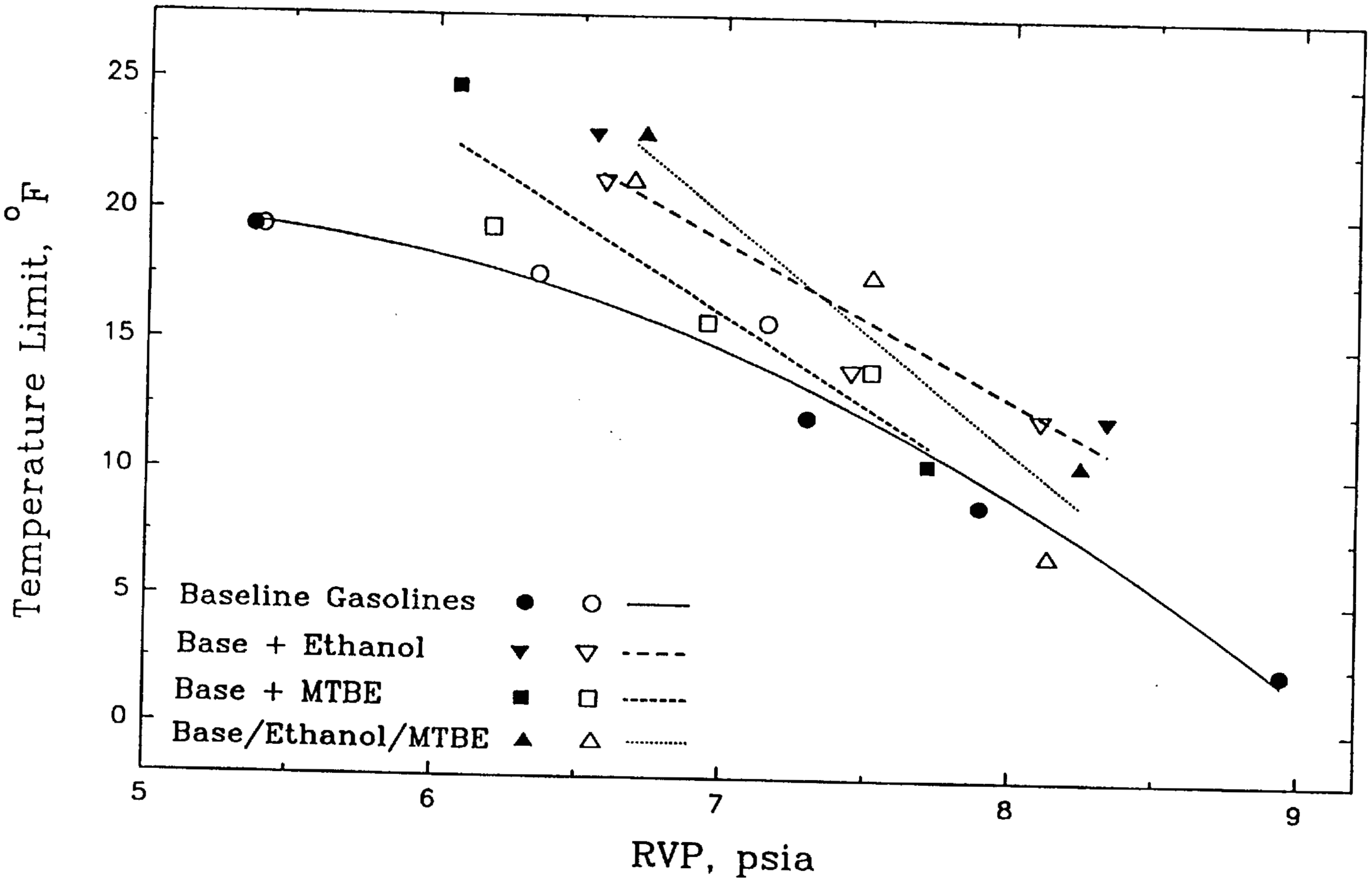


Figure 3-4. The effect of RVP on the upper and lower temperature limits of flammability of all the test fuels



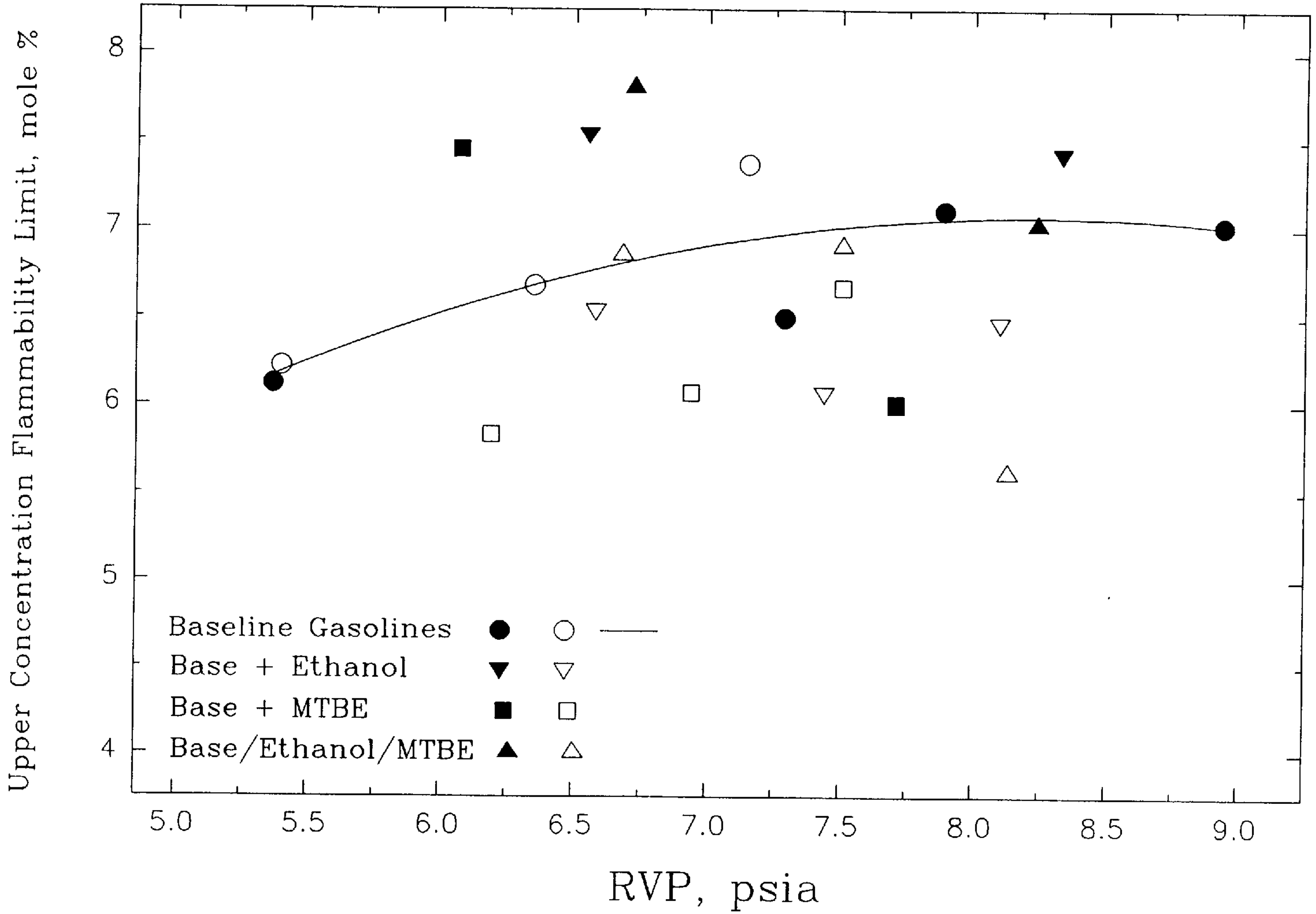
(Filled symbols are high C_5 fuels prepared by SwRI. Open symbols are high C_4 fuels prepared by PPC.)

Figure 3-5. **The effect of RVP on the upper temperature limits of flammability of the gasoline test fuels**

to 8.0 psi RVP. Furthermore, the upper temperature limits of the fuels containing ethanol are 4.3°F higher on average than those of the baseline gasolines over the same RVP range. The increases in upper flammability limits resulting from the addition of oxygenates were not evaluated for statistical significance. The results are, however, consistent with the understanding that oxygenates have wider flammability limits than neat hydrocarbons. The indications are that MTBE has only a small effect while ethanol appears to raise the upper temperature limit of flammability more substantially. MTBE tends to raise the temperature limits at low RVP but has little effect, if any, at RVPs greater than 7 psia. It should be noted that the departure of the regression line for the MTBE-blended fuels from the temperature limit curve for the baseline gasolines is strongly dependent on the test results for fuel FL2407B. Further investigation would be required to determine whether the measured temperature limit for fuel FL2407B is reliable.

The addition of MTBE to the baseline gasoline FL2407 to produce fuel FL2407B had a stronger impact on the upper temperature limit of flammability than did the addition of MTBE to FL2223 to create the oxygenated blend of similar RVP, fuel FL2223B. This disparity was not observed in the fuels containing ethanol (FL2407A and FL2407C; FL2223A and FL2223C). The basic difference between the FL2407 and the FL2223 fuel groups is that the latter had a much higher C_5-to-C_4 ratio than the former. Whether or not the difference in C_5-to-C_4 ratio influenced the flammability of FL2407B is, however, purely speculative.

Figure 3-6 shows the effect of RVP on the <u>calculated</u> upper concentration limits of flammability. The curved line shown in the figure is a polynomial fit of the data on the seven baseline gasolines. It is intended only to serve as a reference for evaluating the effects of changes in fuel composition relative to the baseline gasolines. The non-linearity of the polynomial fit reflects the dependence of the UTLF on vapor composition as well as vapor pressure. The vapor generated from low RVP fuels will contain a greater proportion of higher molecular weight hydrocarbons than the vapors from high RVP fuels. As molecular weight increases, the upper concentration flammability limit decreases. This



(Filled symbols are high C_5 fuels prepared by SwRI. Open symbols are high C_4 fuels prepared by PPC. The curve through the upper concentration limits is a polynomial fit of the seven baseline gasolines.)

Figure 3-6. **Calculated upper concentration limits of flammability of the test fuels**

is illustrated in Figure 3-6 which shows that the UCLF for the baseline fuels drops in a non-linear fashion as RVP is reduced.

There are no indications in Figure 3-6 that either the temperature limits or the concentration limits are significantly affected by the ratio of C_5-to-C_4 components in the fuels. In addition, Figure 3-6 also indicates that there is no particular trend in the calculated UCFL data related to oxygenate type in comparison to the baseline gasolines. If anything, the base + MTBE blends tend to have lower concentration limits than the baseline gasolines, except for the PPC fuel FL2407B with 15 vol % MTBE and an RVP of 6.07 psi. (As noted above, fuel FL2407B also appears to generate an unusual result for the upper temperature flammability limit.) It is important to note, however, that this observation is based on calculated values of the UCLF (from the vapor pressure versus temperature relationships at the UTLF). A more definitive finding concerning oxygenate effects must be based on empirical measurements of the UCLF. These measurements are a key element of Phase II of the study (and are presented and discussed in Section 4 of this report).

Section 4
PHASE II STUDY

This section presents and discusses the vapor phase hydrocarbon concentration measurements that were performed at the UTLF of each test fuel in Phase II of the study. It also presents the results of an assessment of fuel-air mixture stratification in a fuel tank.

VAPOR PHASE SPECIATION

The purpose of vapor phase speciation was to determine if there is a consistent relationship among the UTLF measured in Phase I, the fuel vapor concentrations, and flammability limit data in the literature. Two procedures differing in apparatus and gas sampling methods were performed for the collection of test fuel vapors to be speciated. The first procedure involved the collection of fuel vapors with a gas syringe and the subsequent injection of the sampled vapors into a gas chromatograph (GC) for analysis. This method was discarded after additional investigation revealed that it resulted in unacceptably low sample recoveries, particularly of the heavier hydrocarbon and oxygenate species. The second procedure essentially eliminated the use of a syringe as the vapors were sampled on-line directly to the sample loop of the GC. The latter procedure and the associated results are described below.

Apparatus and Procedures

Vapors for speciations were generated in the combustion vessel shown previously in Figure 3-3. This vessel, a 500-mL three-neck round bottom pyrex flask, was used to measure the temperature limits of flammability of the test fuels. It contained electrodes for ignition and thermocouples for measuring fuel temperature. The only change required for speciation of the fuel-air mixture in the vessel was to exchange the igniter electrodes for a gas sampling probe. The three ports in the combustion vessel were closed with rubber stoppers. Thermocouples and the sampling probe were passed into the vessel through the rubber stoppers of two of the ports while still maintaining a tight seal. The third port was used to fill the vessel with fuel.

The fuel vapor/air mixture sample was extracted at the location of the spark-gap. The sampling probe was a 0.062-in. I.D. stainless steel tube that led directly from the spark-gap location to the sample loop of the gas chromatograph. The sample line between the combustion vessel and the sample loop was heated to approximately 130°F.

The protocol for generating fuel vapors to be speciated was similar to that used in measuring the temperature limits of flammability. In other words, the fuel vapor/air sample was extracted from the vessel under the same conditions and time that would have existed in an ignition test when the spark source was initiated.

The combustion vessel was first placed in a cold bath maintained at the UTLF that was determined in the Phase I study. Twenty-five milliliters of fuel, which had been refrigerated ($\approx$ 40°F), were transferred to the combustion vessel with a pipet. The vessel was sealed and shaken gently to wet the walls and increase liquid-vapor phase equilibration. The apparatus stood for approximately 30 minutes or until the fuel cooled to the bath temperature. Then the vessel was again shaken gently and left to stand 25 minutes longer before a fuel vapor/air mixture sample was extracted. The pressure in the vessel was always atmospheric because the sample line vented to the atmosphere on the downstream side of the sample loop. Samples of 3 cc were taken from the vessel and drawn through the sample loop by drawing a partial vacuum on the atmospheric vent. The gas in the sample loop was allowed to equilibrate to atmospheric pressure before the loop was transferred into the column flow of the gas chromatograph.

Analytical Method

The analysis was performed with a Hewlett-Packard model 5890 gas chromatograph equipped with a 105 m × 0.25 mm capillary column from Restek Corporation and a flame ionization detector (FID). Two gas sample loops with volumes of $\approx$ 0.25 cc and $\approx$ 0.05 cc were used to quantify the amount of sample analyzed. Data processing was performed with a Chrom Perfect data acquisition system designed to handle the analysis of complex hydrocarbon mixtures. Hydrocarbon calibration standards were purchased from Supelco, Inc. The temperature program for the chromatograph started at 5°C and held for 10 minutes. Then the temperature increased 5°C per minute and held at 50°C until the total retention time was 43 minutes. Finally, the temperature increased 1.6°C per minute and held at 200°C for 5 minutes. The total duration of the program was 141.75 minutes for speciating liquid gasoline samples. For vapor phase samples composed of lower molecular weight species, the program duration was reduced to 100 minutes.

Gas standards containing methane, ethane, propane, and butane in concentrations ranging from 0.1 to 6.0 mole % were used to calibrate the gas chromatograph. Analyses of samples containing 0.3 to 8.0 mole % butane in nitrogen showed a linear FID response in that range. The calibration data were used with relative FID response factors and molecular weights to calculate calibration factors for all the species of interest.

Speciation Results

The speciations of the test fuels were performed at the upper concentration limits of flammability (UCLF) which occur at the UTLF. The measured UCLF are compared with calculated equilibrium values in Table 4-1. The calculated UCLF were determined using the vapor pressure expressions shown earlier in Table 3-3. The measured UCLF were derived from the detailed speciation data. The detailed speciation data are tabulated in Appendix F.

The calculated UCLF of the baseline gasolines in Table 4-1 agree reasonably well with those determined by measurement. For the baseline gasolines, the measured UCLF values were slightly higher than the calculated values. The trend is similar, but the differences are more substantial for the ethanol/base gasoline blends (designated with the letter "A" in the fuel codes shown in Table 4-1). The measured UCLF are on the order of 3 mole % higher in most cases. The measured UCLF of the gasolines containing MTBE (designated as "B" fuels in Table 4-1) also were consistently higher than those

Table 4-1. Temperature and Concentration Limits of Flammability				
Test Fuel Code	RVP, psia*	Measured UTLF, °F*	Calculated UCLF, mole %*	Measured UCLF, mole %
FL2221	7.15	15.8	7.37	8.13
FL2222	6.35	17.6	6.68	8.00
FL2223	5.40	19.4	6.22	6.74
FL2407	5.37	19.4	6.12	7.64
FL2408	7.29	12.2	6.50	6.57
FL2409	7.89	8.8	7.11	7.05
FL2410	8.94	2.3	7.02	6.77
FL2221A	8.10	12.2	6.47	9.45
FL2222A	7.44	14.0	6.07	8.98
FL2223A	6.58	21.2	6.54	9.62
FL2407A	6.55	23.0	7.54	10.93
FL2408A	8.33	12.2	7.43	8.04
FL2221B	7.51	14.0	6.67	8.34
FL2222B	6.94	15.8	6.07	8.00
FL2223B	6.19	19.4	5.83	8.01
FL2407B	6.07	24.8	7.45	8.58
FL2408B	7.71	10.4	6.01	7.04
FL2221C	8.13	6.8	5.62	7.33
FL2222C	7.51	17.6	6.91	9.75
FL2223C	6.68	21.2	6.86	9.50
FL2407C	6.72	23.0	7.81	10.03
FL2408C	8.24	10.4	7.03	6.72

* Values taken from Table 3-3.

calculated at equilibrium. In this case the measured UCLF ranged from 1 to 2 mole % higher than the calculated values. For the MTBE/ethanol/gasoline blends ("C" fuels), the measured UCLF were higher than the calculated UCLF by amounts that were typically in between the differences exhibited by the ethanol and MTBE blends -- averaging about 2.0 mole % higher.

The cause of the discrepancy between the calculated and the measured UCLF values was not investigated. However, this discrepancy may be a result of the non-ideal nature of ethanol. Since ethanol is so non-ideal, it comprises a disproportionate fraction of the vapor space. The effect of the non-ideal behavior of ethanol is felt most strongly in the low RVP fuels where the fraction of ethanol in the vapor phase is the highest. This is demonstrated in Figure 4-1 which shows the concentrations of ethanol and MTBE in the vapor phase as a function of RVP. The vapor phase concentration of ethanol increases much more sharply than that of MTBE as RVP is decreased.

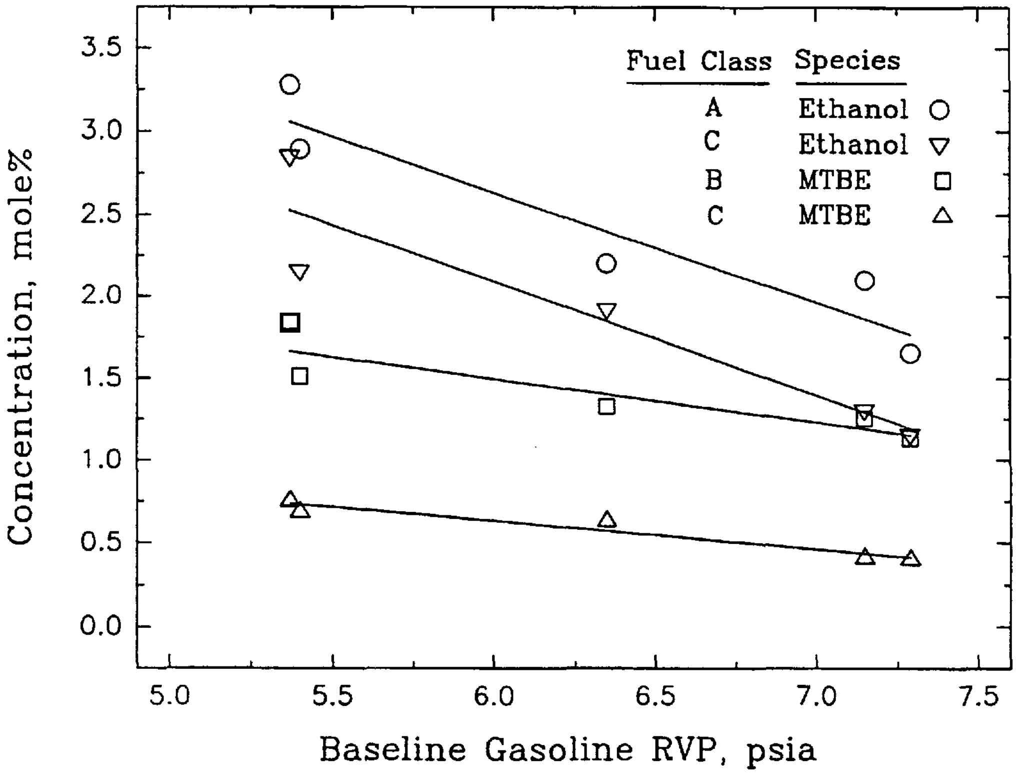


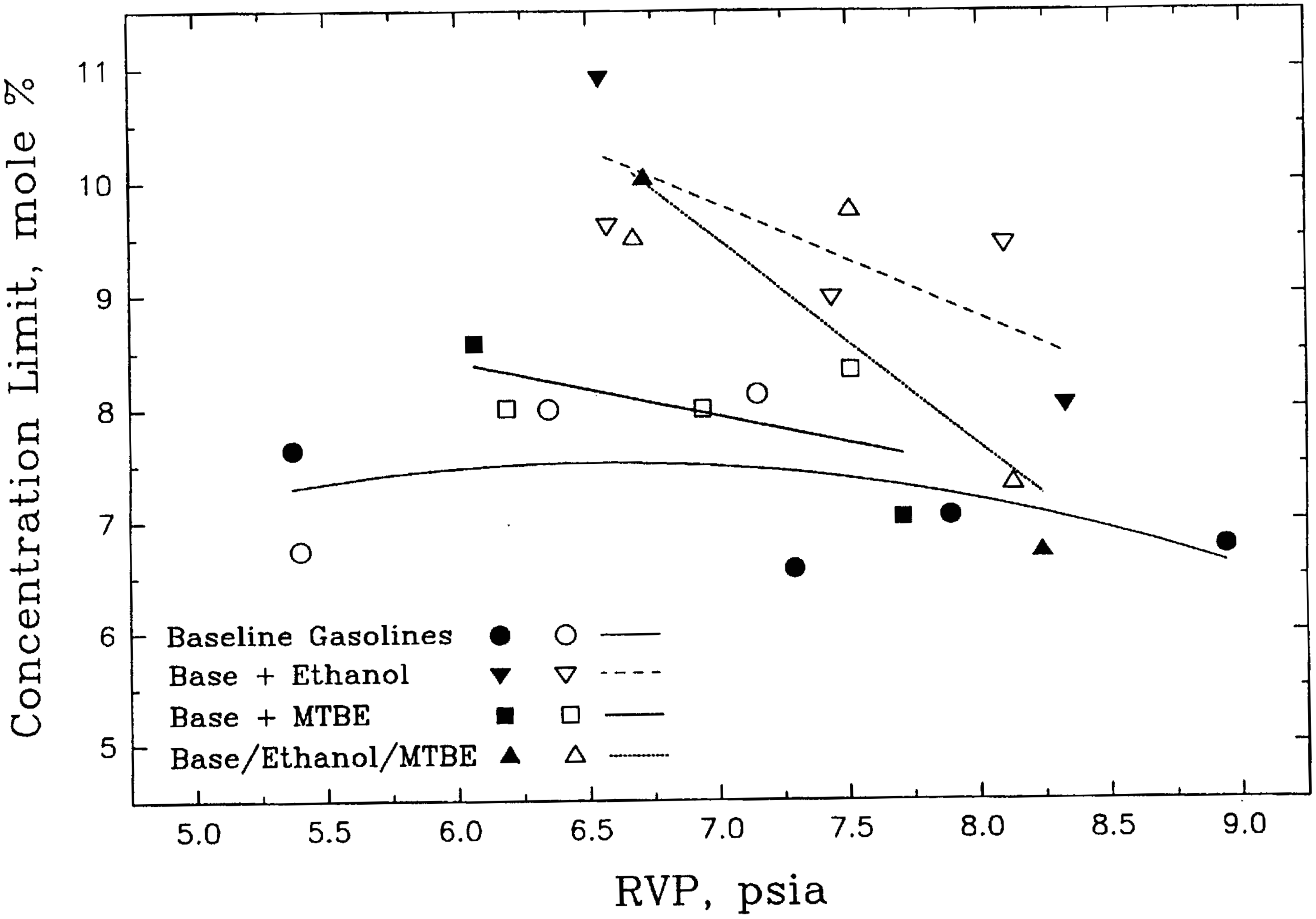
Figure 4-1. The effect of fuel RVP on the vapor phase concentrations of ethanol and MTBE

It is believed that the measured values of UCLF are more accurate than the calculated values of UCLF (from the vapor pressure versus temperature relationships at the UTLF). The belief is based on the fact that ethanol causes non-ideal behavior and that vapor pressure is a bulk property that may not accurately reflect vapor concentration if the liquid fuel composition is significantly altered.

Figure 4-2 plots the UCLF of the test fuels (using the measured values) versus RVP. The figure shows that fuel C_5-to-C_4 ratio has no consistent effect on UCLF when comparing fuels of similar RVP levels. However, the results do indicate that ethanol has a substantial effect on the UCLF while MTBE has a modest effect on the UCLF at equivalent RVP levels. Fuels containing ethanol have upper concentration limits of flammability that are as much as 2.5 mole percent higher than those of the baseline gasolines. The UCLF of the MTBE/base gasolines are less than 1 mole percent higher than those of the baseline gasolines.

The increased concentrations of ethanol and MTBE with reduced RVP closely track the deviations of the UCLF of the ethanol and MTBE blends from the UCLF of the baseline fuels. Because the stoichiometric fuel-air ratio of ethanol (and MTBE) is much higher than that of a typical hydrocarbon, an increase of ethanol in the vapor phase will raise the UTLF. (A higher concentration of vapor is needed to reach the rich limit.)

Since an increase in the UCLF should correspond with an increase in the UTLF at constant RVP, the trends in the UCLF versus RVP should be similar to that of the UTLF versus RVP. A comparison of Figures 4-2 and the upper temperature flammability limits illustrated previously in Figure 3-5 shows that the measured UCLF correspond most favorably with the UTLF data. On the other hand, the calculated UCLF (shown previously in Figure 3-6) do not show an incrase in the UCLF with oxygenated fuels. This result further supports the conclusion that the measured values of UCLF are more reliable than the calculated values.



(Filled symbols are high C_5 fuels prepared by SwRI. Open symbols are high C_4 fuels prepared by PPC.)

Figure 4-2. Measured upper concentration flammability limits of the gasoline test fuels

STRATIFICATION

There have been various reports of stratification of the fuel vapor/air mixture in fuel tanks. However, few studies have been conducted to address the possibility of fuel vapor stratification. Griffith(9) found significant stratification of the fuel vapors from both gasoline and methanol in a 20-gallon fuel tank with a depth of approximately 12 in. His experiments were performed in a constant temperature environment, free of temperature gradients. More than enough time, i.e., 12 hours, was allowed to establish vapor-liquid equilibrium before the vapor space analysis was performed.

Stratification results from the ingestion of air into the vapor space of the fuel tank, and this produces gradients in the fuel vapor/air mixture due to the lower concentration of hydrocarbon vapors. Instead of the uniform, equilibrium fuel/air ratios considered up to now, there will be a continuous range of mixture ratios. The range can vary from 100% air (no hydrocarbon vapor) up to the full equilibrium fuel/air concentration ratio. Therefore, if stratification of the fuel-air mixture in a fuel tank occurs, then the potential fuel tank flammability condition would be more difficult to predict than if only the equilibrium vapor pressure data and upper temperature limits of flammability were being considered.

From the standpoint of basic physics, stratification of fuel vapor should not occur over the vertical distance (≈ 9 in.) from the top of the fuel tank to the liquid fuel. The potential energy differences of molecules over small distances are much less than their kinetic energies, so simple diffusion and Brownian motion dissolve concentration gradients. The only plausible explanation for stratification in fuel tanks is that it takes much longer to reach vapor-liquid equilibrium than is expected.

General Approach

The question of stratification was addressed in three experiments that determined the time required to achieve vapor-liquid equilibrium and identified the conditions that could cause vapor phase stratification in fuel tanks. Two of the experiments were performed in a cylindrical-shaped, 8-L vessel approximately 16 cm in diameter and 40 cm in height. The third experiment was performed in a fuel tank. Fuel vapor/air concentrations were measured in the fuel tank over a diurnal cycle ranging from 60 to 84°F. Diurnal cycles produce two phenomena in a fuel tank: (1) changes in equilibrium vapor concentrations that are related directly to vapor pressure, and (2) air ingestion due to ambient temperature reductions.

Experiment I

The objective of this experiment was to determine the effect of temperature on the concentration of fuel vapor approximately 30 cm above the liquid fuel as a function of time. The 8-L vessel was filled with 1 liter of the 5.4 psi RVP base fuel (FL2407) and sealed with a rubber stopper to prevent vapors from escaping. The rubber stopper was equipped with ports to allow insertion of a thermocouple (to measure fuel temperature) and a gas sampling probe. The vessel was kept overnight in a fuel storage facility that was maintained at 45°F. The next morning, the vessel was promptly brought into a laboratory maintained at approximately 76°F and placed beside the gas chromatograph. As the temperature of the liquid fuel in the vessel rose due to the warmth of the laboratory environment, the equilibrium vapor concentration also increased. The time required for the vapor concentration to reach equilibrium provided a measure of its diffusion rate.

Gas samples and temperature readings were begun 15 minutes after the vessel was taken from the cold box and set beside the gas chromatograph. A gas sampling probe and thermocouple were inserted into the vessel through the ports in the rubber stopper. The probe was positioned to extract gas samples 30 cm above the liquid fuel and 5 cm from the ceiling of the vessel. The gas samples could be taken only at two-hour intervals because 100 minutes were required to complete the chromatographic analysis. Consequently, it was necessary to repeat the experiment three times to gather data points at time intervals less than 100 minutes. A complete speciation of the fuel vapor was performed on each gas sample. The speciation data are tabulated in Appendix G.

Figure 4-3 shows histories of the fuel temperature, the measured fuel vapor concentration, and the calculated equilibrium fuel vapor concentration. The fuel vapor concentrations were determined from the speciation analysis, and the equilibrium fuel vapor concentration was calculated using the fuel temperature. The temperature in the laboratory ranged from 75 to 77°F. Figure 4-3 shows that fuel temperature reaches the ambient temperature in approximately 3 hours, while it takes close to 7 hours for the fuel vapor concentration to reach equilibrium.

Figure 4-4 shows a similar history of the fuel vapor concentration as a percentage of the equilibrium concentration. In Figure 4-4, the term "% of Equilibrium" is equal to [100 × (measured/equilibrium) concentration]. It is seen that equilibrium is approached slowly while the fuel is warming up, but it then rises rapidly after the fuel reaches ambient temperature. The S-shaped curve for the "% of Equilibrium" arises because the fuel temperature equilibrates much more quickly than the fuel vapor concentration.

Experiment II

Experiment II was performed to determine the time necessary to reach vapor-liquid equilibrium in a fuel tank at constant temperature. Except for slight modifications in the apparatus, Experiment II was performed in much the same way as Experiment I. The location of the sampling probe in the 8-L vessel and the analytical procedures were identical in both experiments.

The initial conditions created for the experiment were such that the 8-L vessel contained 1 L of fresh fuel, while the remaining space in the vessel was completely free of hydrocarbon vapors. This was accomplished by inserting a dip tube through the rubber stopper to within 3 mm of the bottom of the vessel. One liter of fuel FL2408 stored in a separatory funnel was connected to the dip tube and placed above the 8-L vessel.

Before the experiments were started, the vessel was cleaned and purged with fresh air, and the fuel in the separatory funnel was set at room temperature (75 ± 1°F). The

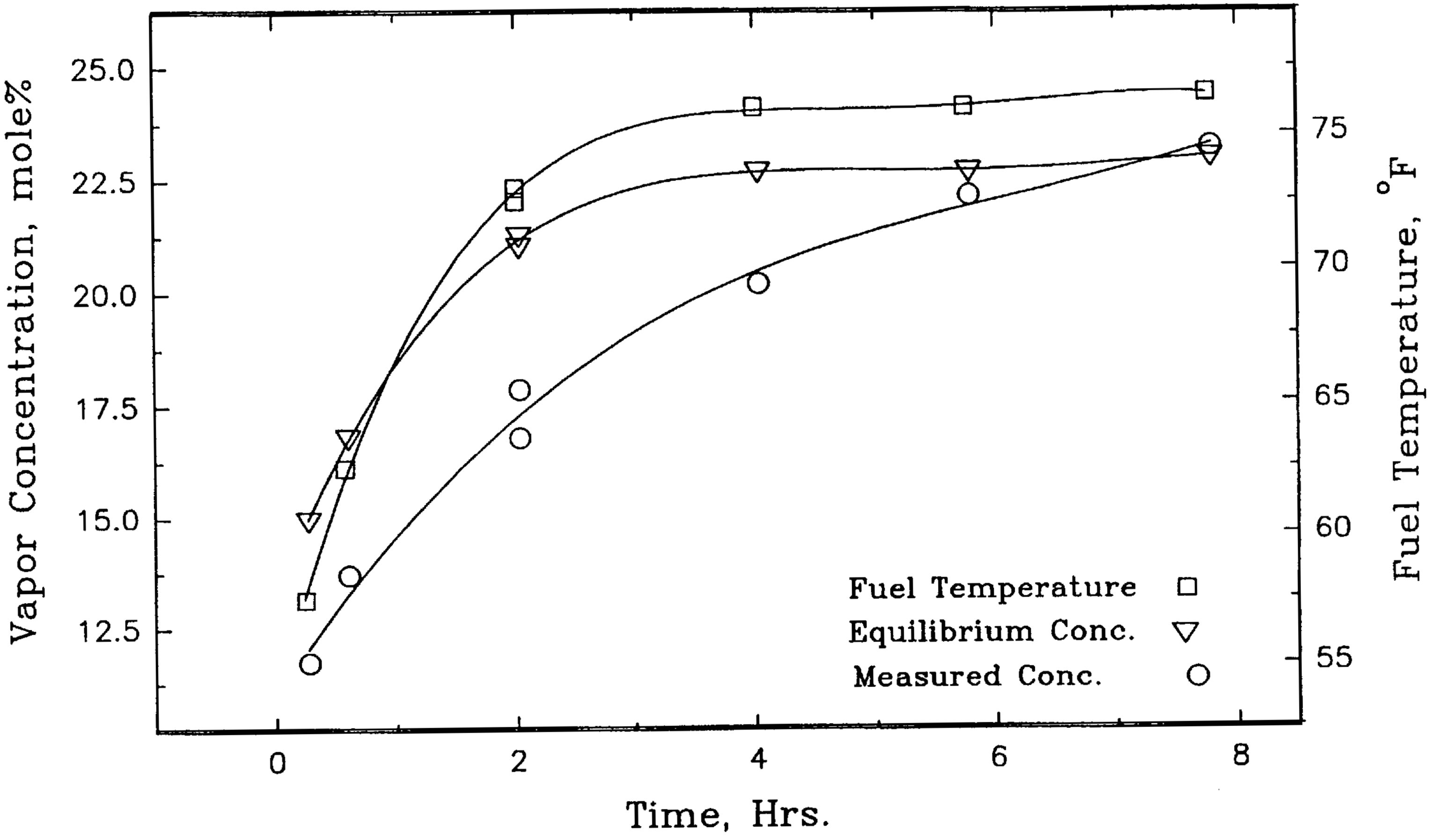
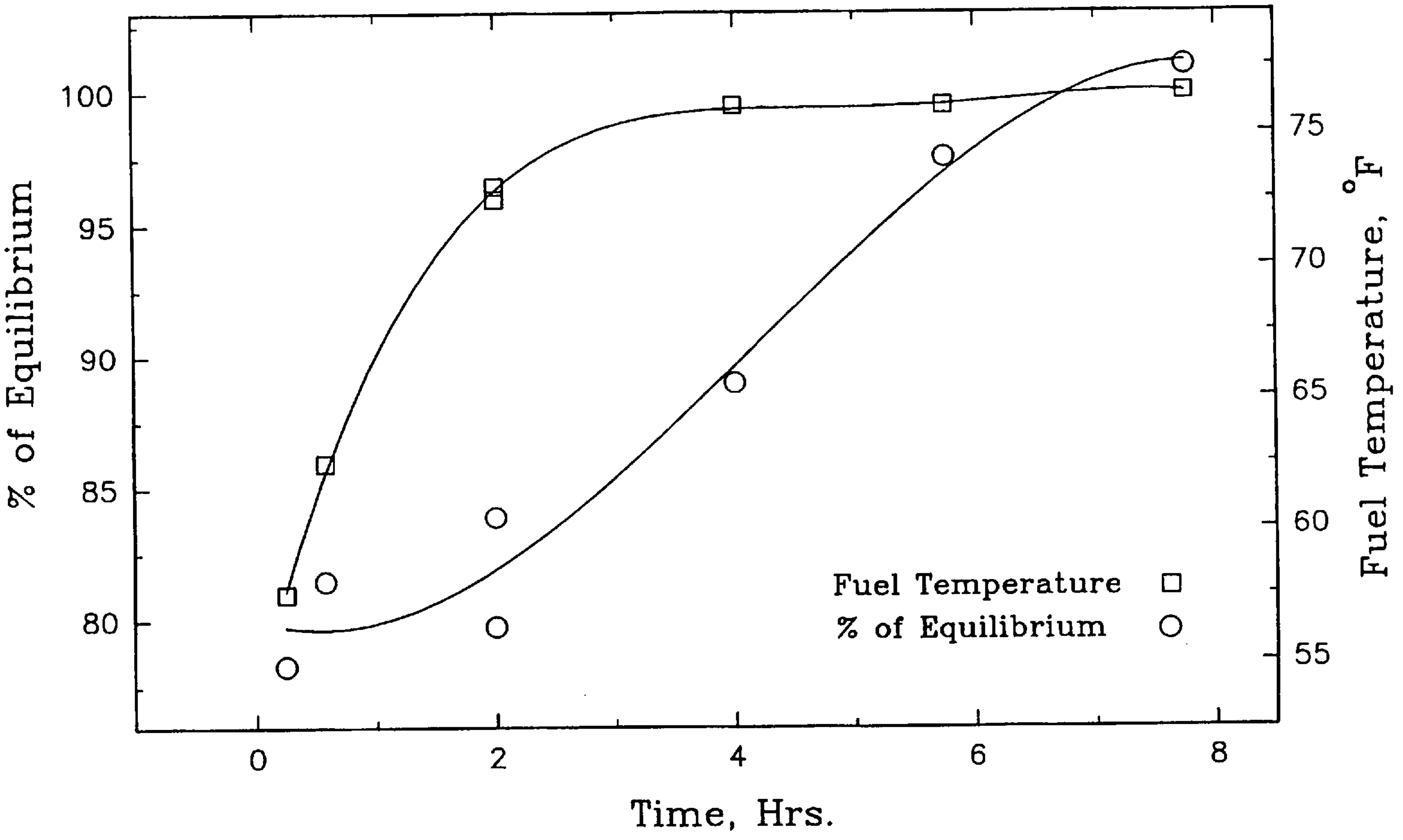


Figure 4-3. Fuel temperature and vapor concentration history in a vessel that has been pre-cooled to 45°F and allowed to warm to room temperature



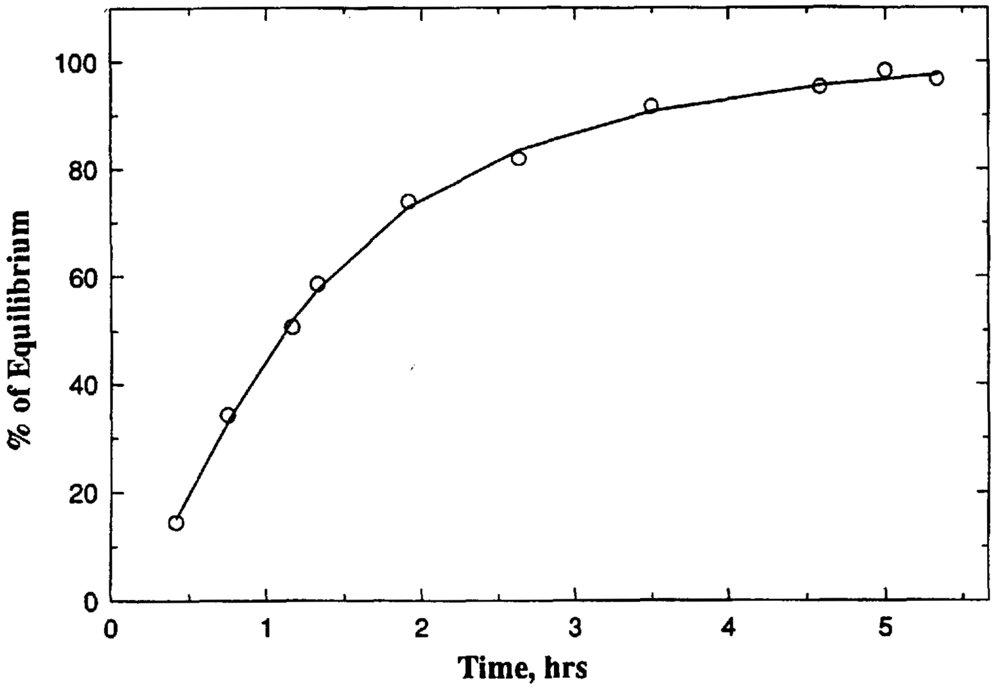
(The % of equilibrium is 100 times the quotient of the measured and equilibrium concentrations.)

Figure 4-4. <u>**The time dependencies of the fuel temperature and the percent of vapor-liquid equilibrium in a vessel that has been pre-cooled to 45°F and allowed to warm to room temperature**</u>

experiment then commenced as the separatory funnel stopcock was opened, allowing fuel to flow into the vessel. After 2 minutes, there was a stagnant pool of fuel in the vessel.

Fuel vapor/air samples were extracted from the vapor space at various time intervals to determine the fuel vapor concentration-time profile at a central location, 30 cm above the fuel and 5 cm from the ceiling of the vessel. As each gas chromatographic analysis took approximately 2 hours to perform, the experiment had to be conducted several times to obtain fuel vapor concentrations at closer time intervals. The results of the speciation analysis are given in Appendix G.

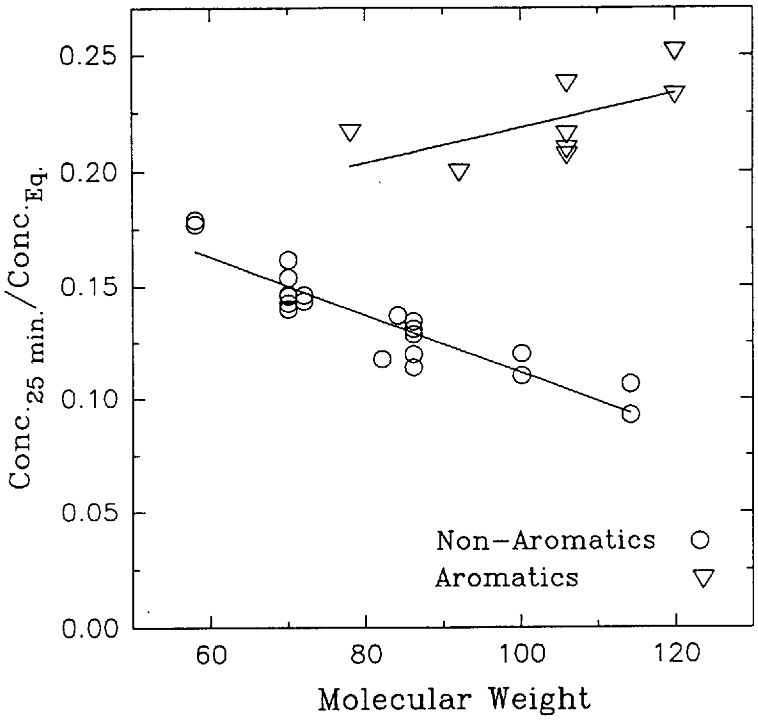
Figure 4-5 shows the concentration versus time profile of the fuel vapor at the sampling point. The figure shows that the vapor-liquid equilibrium in the vessel is achieved in about 4.5 hours at 75°F. Since the sampling point is near the ceiling of the vessel, equilibrium throughout the vapor space is reached in essentially 4.5 hours.



(The vapor concentration begins at zero and builds with time to approach equilibrium.)

Figure 4-5. The time dependence of the percent of vapor-liquid equilibrium in a vessel at constant temperature (75°F)

The rate at which equilibrium is reached depends on the rates of diffusion of the various species in the fuel. The ratio of the species concentration at 25 minutes to that at 5 hours is plotted against the molecular weight in Figure 4-6. One of the curves shows the dependence on non-aromatic hydrocarbons, mostly isoparaffins, and the second curve shows the dependence on aromatics. Only the abundant species in the fuel are plotted in the figure. Since lower molecular weight species are expected to diffuse faster than heavier species, the concentrations of the lighter species should be relatively higher after 25 minutes than after 5 hours when equilibrium is reached. The predicted trend is observed for the non-aromatic species but not for the aromatics. The aromatics (benzene through isopropyl benzene) appear to diffuse at similar rates.



(The ratio of the concentration measured at 25 minutes after the fuel is placed in the vessel to the equilibrium concentration is plotted vs. molecular weight.)

Figure 4-6. The effect of molecular weight on the rate of diffusion of species into the vapor space

Fuel Tank Test

The purpose of this test was to determine how the composition of gasoline vapors in the vapor space of a fuel tank varies over a 60 to 84°F diurnal cycle. The objective was to determine if there is significant fuel vapor dilution when the temperature decreases and air is drawn into the tank. The combined effects of fuel cooling and dilution of fuel vapors with air could result in flammable vapor concentrations at temperatures higher than the equilibrium UTLF.

Test Cell

The fuel tank test was performed in a temperature-controlled emissions enclosure (TCEE) developed to investigate variables that affect vehicle emissions over a wide range of temperature conditions. The temperature in the TCEE is maintained by a water-fed, air-blown heat exchanger. The water for the heat exchanger is either heated or cooled externally to the TCEE. This method of temperature control is used to prevent hydrocarbon or freon contamination of the TCEE. Temperature control is performed by a computer system. For this work, the TCEE was programmed to run a standard EPA diurnal cycle in the 60 to 84°F range.

Fuel Tank

A fuel tank from a Chevrolet CK1500 pickup truck was chosen for the test. The tank was about 50 percent larger than that of the average automobile, with a 30-gallon capacity, a depth of 14.5 in., and a length of 58 in. An oversized fuel tank was chosen to create a worst-case scenario: temperature change causes the fuel tank to breathe where the amount of air exchanged is proportional to the tank volume. Since air enters the tank through the filler cap and the vapor canister vent, an increased air flow in those locations is expected to cause increased stratification.

The vapor canister was also removed, leaving the canister vent line open to receive fresh air. Had the canister been attached, the air could have become enriched with fuel vapors as it was drawn into the tank. That would have reduced stratification and lowered the likelihood of reaching a flammable condition. Four thermocouples were placed in the tank. These were used to measure the liquid fuel temperature, the fuel-air mixture temperature 2 in. below the top of the tank, and the external surface temperatures at the top and bottom of the tank. Fuel-air mixtures were withdrawn from the tank through a 0.62-in. I.D stainless steel sampling probe at approximately 2 in. from the top of the tank. The samples were extracted from the vapor space with a 5-cc gas syringe. The tank was filled with 4 gallons of test fuel FL2408B, which consisted of 15 vol% MTBE in the FL2408 baseline gasoline.

Procedure

The fuel tank was placed in the TCEE and filled with 4 gallons of fuel 5 hours before the test was scheduled. At that time, the fuel temperature was approximately 78°F and the air temperature in the TCEE was set to 80°F. The initial temperature readings are given in Table 4-2. The vapor space in the tank was sampled at the start of the test and at increments of 2 to 3 hours throughout the test.

The sampling procedure began with the attachment of the syringe to the sampling probe. Two cubic centimeters of the fuel-air mixture was withdrawn from the fuel tank. The syringe was removed from the probe, and the gas sample was exhausted from the syringe. The syringe was then reattached to the probe and 5 cc of sample withdrawn from the fuel tank. A complete hydrocarbon species analysis was performed on the contents of the syringe.

Results

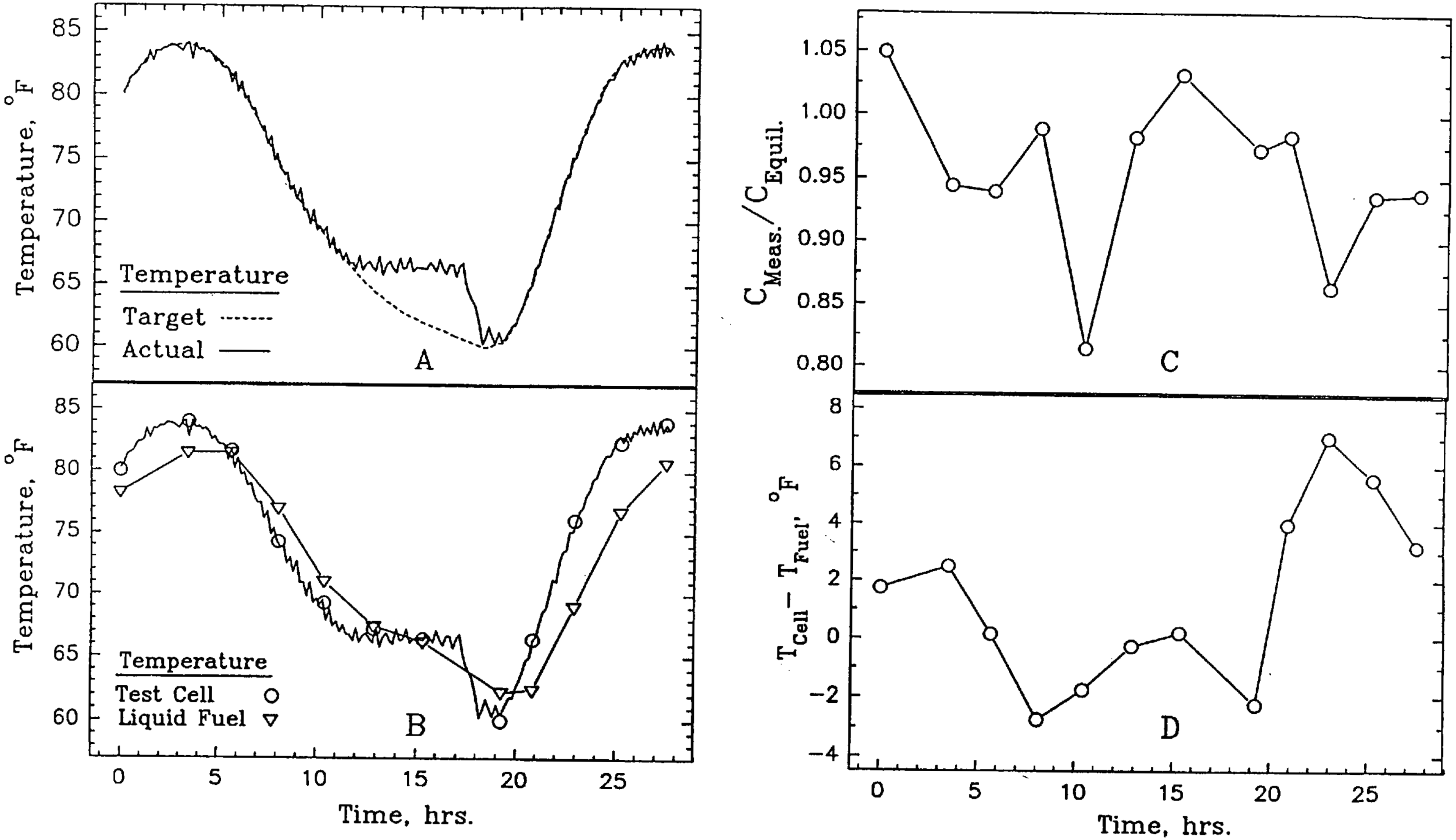
The test results are given in Table 4-2 and in Figs. 4-7A, 4-7B, 4-7C, and 4-7D. Table 4-2 gives measured and calculated equilibrium fuel vapor concentrations along with temperature conditions of the fuel tank and TCEE at each sampling time. The measured fuel vapor concentration was determined by summing up the individual concentrations of fuel vapor species given in Appendix H. The equilibrium concentrations were calculated assuming vapor-liquid equilibrium at the liquid fuel temperature.

Table 4-2. Fuel Vapor/Air Mixture Analysis in a Fuel Tank Over a Diurnal Cycle in the 60 to 84°F Range

Test Time, hr	Measured Temperatures, °F					Concentrations, mole%	
	Test Cell	Liquid Fuel	Vapor Phase	Tank Skin Top	Tank Skin Bottom	Measured	Equilibrium
0	80.00	78.26	78.08	79.52	78.08	36.55	34.83
3.47	84.00	81.50	82.04	83.12	81.68	35.16	37.24
5.67	81.64	81.50	80.42	81.50	81.14	34.99	37.24
8.05	74.25	77.00	75.20	75.20	75.92	33.54	33.93
10.38	69.30	71.06	69.26	69.44	70.16	24.33	29.88
12.88	67.20	67.46	66.20	66.92	66.92	27.10	27.60
15.30	66.40	66.20	65.48	66.02	66.56	27.68	26.84
19.25	60.00	62.24	60.80	61.16	61.52	23.85	24.53
20.83	66.40	62.42	63.86	62.96	65.30	24.21	24.63
22.92	76.10	69.08	72.14	74.12	70.16	24.70	28.61
25.22	82.40	76.82	79.52	80.78	77.72	31.64	33.80
27.50	84.00	80.78	81.68	82.94	81.14	34.45	36.70

Comparison of the actual and target diurnal temperature profiles in Fig. 4-7A shows that the temperature drifted off target for a period of approximately 5 hours. A malfunction that developed in the water cooling system was corrected as soon as it was noticed by adding ice to the water supply for the heat exchanger. The target minimum temperature of 60°F in the TCEE was attained, and the balance of the test followed the targeted profile.

Figures 4-7B and 4-7D compare the air temperature in the TCEE with the liquid fuel temperature. These figures show that the fuel temperature lags behind the temperature



(A – Compares actual temperature in TCEE with target temperature of the diurnal cycle; B – Compares temperature in TCEE with liquid fuel temperature; C – History of the fuel vapor concentration ratio (measured/equilibrium); D – History of the difference between TCEE-air and liquid fuel temperatures.)

Figure 4-7. Fuel tank test results

of the air by about 2 hours during periods of rapid temperature change in the TCEE. Because of the time lag, the minimum and maximum fuel temperatures are not as great (lower maximum/higher minimum) as the air temperature. These time lags between the vapor and liquid temperatures agree with those previously described for Experiment I. As noted earlier, fuel-vapor concentrations were calculated assuming vapor-liquid equilibrium at the liquid fuel temperature recorded at each sampling time point. (See Table 4-2.) Figure 4-7C shows the time history trend of the ratio of the measured fuel vapor concentration to the equilibrium fuel vapor concentration. There are two reasons for the measured concentration to be lower than the equilibrium concentration: 1) when the ambient temperature is decreasing, fuel vapor is diluted by air entering the fuel tank, and 2) when the ambient temperature is increasing, the equilibrium of the air/vapor phase mixture does not keep pace with the equilibrium vapor concentration of the liquid phase. These phenomena are explained below.

Figure 4-7C shows a significant decrease in the ratio of measured to equilibrium fuel vapor concentration at 10 hours into the test. This decrease in the relative fuel vapor concentration is caused by the passage of fresh air into the tank. Lowering the temperature in the tank causes a partial vacuum that draws in air through the check valve in the filler cap and the open vapor canister line.

Figure 4-7C also shows that the ratio of the measured to equilibrium fuel vapor concentration decreases in the period from 20 to 23 test hours. During this period, the air and fuel temperatures are both rising rapidly. The decrease in the ratio of measured to equilibrium fuel vapor concentration is caused by a time lag associated with achieving vapor-liquid equilibrium, as diffusion is not instantaneous (see Experiment II).

Whether it be air dilution or a time lag in achieving equilibrium, this test shows that the actual vapor phase concentration never falls below 80 percent of the equilibrium fuel vapor concentration during the diurnal cycle. Furthermore, Figure 4-7B shows that the lowest liquid phase temperature reached during the diurnal cycle is higher than the minimum ambient temperature. In addition, the departures from equilibrium, which are affected by dilution and slow molecular diffusion, only occur when there are rapid changes in the temperature of the test cell. The temperatures where rapid changes occur are higher than the minimum fuel temperatures. This means that air dilution and slow molecular diffusion are greatest at higher daily ambient temperatures. However, flammable conditions (UCLF) due to dilution are less likely to be achieved at higher temperatures than at daily minimum temperatures where only minimal dilution occurs.

Section 5

SUMMARY OF KEY FINDINGS

The results of this study show the following:

- The temperature limits of flammability correlate with RVP. The upper flammability temperature limits increase as RVP is reduced. The temperature limits for non-oxygenated fuels correlate well with prior studies. The addition of either MTBE or ethanol or both to gasoline yields a moderate increase in upper flammability limits. Gasoline blends containing ethanol, including those commingled with MTBE, elevate the upper temperature limits of flammability to a greater extent than gasoline blends containing MTBE alone. The lower temperature limits of flammability also increase as RVP is reduced, although less markedly than the upper limits.

- The Clausius-Clapeyron relationship accurately defines vapor pressure as a function of the temperature and Reid vapor pressure for each of the test gasoline and gasoline/oxygenate blends.

- A generalized expression for the dependence of vapor pressure on absolute temperature and RVP can be established for each fuel group, i.e., neat gasoline, gasoline/MTBE blends, etc.

- The upper concentration limits of flammability (UCLF) of the gasolines containing ethanol are markedly greater than those containing MTBE or no oxygenates. The UCLF of gasolines containing MTBE are only slightly higher than the limits of the test gasolines containing no oxygenates.

- The ratio of C_5-to-C_4 hydrocarbons in the fuel has no consistent effect on the measured values of either the upper temperature limits of flammability or the upper concentration limits of flammability when comparing fuels at similar RVP levels.

- Stratification of vapors in fuel tanks results from changes in temperature which cause air to enter (or be ingested by) the tank. Deviations of vapor concentrations from equilibrium conditions in a fuel tank are explainable in terms of air ingestion resulting from temperature change and mass transport effects on the re-establishment of equilibrium. At constant temperature, up to 4 hours are required to reach vapor-liquid equilibrium in a closed storage vessel.

- A decrease in temperature causes air to enter and dilute the fuel vapors in a fuel tank. The effect of air dilution on fuel tank vapor concentration is somewhat offset by lags between changes in ambient temperature and fuel temperature which can be as much as 3 hours. When the ambient temperature falls, the reduction in fuel temperature lags behind and this causes the concentration of vapors in the tank to remain higher than the equilibrium concentration for the ambient temperature.

- The air dilution and molecular diffusion associated with a 24-hour diurnal cycle over an 84 to 60 °F ambient temperature range has a relatively small effect on the departure of vapor concentrations in a fuel tank from equilibrium conditions. The vapor concentration does not fall more than 20% below equilibrium levels. The effects of these two phenomena (air dilution and molecular diffusion) on the dynamics of vapor-liquid equilibrium concentrations in a fuel tank are only important (with respect to reaching the UCLF) when there are rapid changes in ambient temperature.

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APPENDIX A

Vapor Pressure Data

Table A-1. Vapor Pressures of Base Fuels

Total Vapor Pressures, psia							
Temperature, °F	FL2221	FL2222	FL2223	FL2407	FL2408	FL2409	FL2410
15	1.07 @ 15.1°F	0.96 @ 16.0°F	0.84	0.81 @ 16.4°F	1.09 @ 17.0°F	1.22	1.57 @ 18.3°F
20	1.19	1.03	0.93	0.94	1.16	1.39	1.64
25	1.36	1.17	1.00	1.00	1.35	1.58	1.86
30	1.54	1.32	1.13	1.13	1.57	1.81	2.10
35	1.75	1.49	1.29	1.31	1.77	2.06	2.38
40	N*	N	N	N	N	2.32	2.68
45	2.22	1.90	1.64	1.67	2.28	2.61	3.02
50	2.49	2.16	1.84	1.87	2.55	2.92	3.39
55	2.80	2.41	2.06	2.10	2.87	3.25	3.76
60	N	N	N	N	N	3.64	4.19
65	3.51	3.06	2.61	2.61	3.54	4.00	4.63
70	4.04	3.56	3.02	2.98	4.11	4.53	5.21
85	5.41	4.78	4.04	N	N	N	N
100	7.07	6.22	5.35	5.37	7.29	8.01	9.13
115	9.08	8.05	6.95	N	N	N	N
130	11.42	10.24	8.91	8.96	12.03	3.20	14.99

* N = No measurement taken

Table A-2. Vapor Pressures of Fuel Blends Containing 10 Percent Ethanol					
	Total Vapor Pressures, psia				
Temperature, °F	FL2221A	FL2222A	FL2223A	FL2407A	FL2408A
15	1.03	0.91	0.77	0.87	1.25 @ 18.2°F
20	1.17	1.04	0.91	1.00	1.33
25	1.36	1.22	1.07	1.15	1.54
30	1.55	1.39	1.22	1.31	1.75
35	1.80	1.60	1.42	1.49	1.99
45	2.32	2.09	1.83	1.91	2.55
50	2.63	2.36	2.07	2.18	2.87
55	2.97	2.68	2.35	2.44	3.22
65	3.76	3.39	3.00	3.15	4.03
70	4.37	3.96	3.49	3.55	4.56
100	8.10	7.44	6.51	6.52	8.44
130	14.02	13.01	11.80	11.84	14.71

Table A-3. Vapor Pressures of Fuel Blends Containing 15 Percent MTBE

	Total Vapor Pressures, psia				
Temperature, °F	FL2221B	FL2222B	FL2223B	FL2407B	FL2408B
15	1.00	0.88 @ 15.5°F	0.74 @ 15.9°F	0.83	1.03 @ 16.7°F
20	1.15	0.99	0.86	0.93	1.17
25	1.33	1.16	1.02	1.07	1.38
30	1.54	1.33	1.16	1.23	1.58
35	1.74	1.54	1.35	1.41	1.81
45	2.23	2.00	1.75	1.80	2.34
50	2.55	2.26	1.99	2.05	2.64
55	2.87	2.55	2.25	2.29	2.97
65	3.61	3.23	2.86	2.93	3.71
70	4.17	3.80	3.36	3.35	4.27
100	7.45	6.86	6.06	5.63	7.71
130	12.24	11.34	10.32	10.15	12.82

Table A-4. Vapor Pressure of Ethanol/MTBE Commingled Fuel Blends					
	Total Vapor Pressures, psia				
Temperature, °F	FL2221C	FL2222C	FL2223C	FL2407C	FL2408C
15	1.04	0.91	0.83 @ 15.6°F	0.94 @ 16.8°F	1.19 @ 17.3°F
20	1.22	1.07	0.96	1.04	1.35
25	1.39	1.25	1.12	1.19	1.54
30	1.60	1.45	1.26	1.36	1.75
35	1.83	1.65	1.46	1.55	1.99
45	2.38	2.12	1.90	1.99	2.55
50	2.67	2.41	2.15	2.25	2.86
55	3.03	2.74	2.41	2.54	3.22
65	3.81	3.44	3.06	3.21	4.02
70	4.42	4.03	3.57	3.65	4.52
100	8.15	7.51	6.64	6.67	8.34
130	13.96	12.98	11.82	11.92	14.42

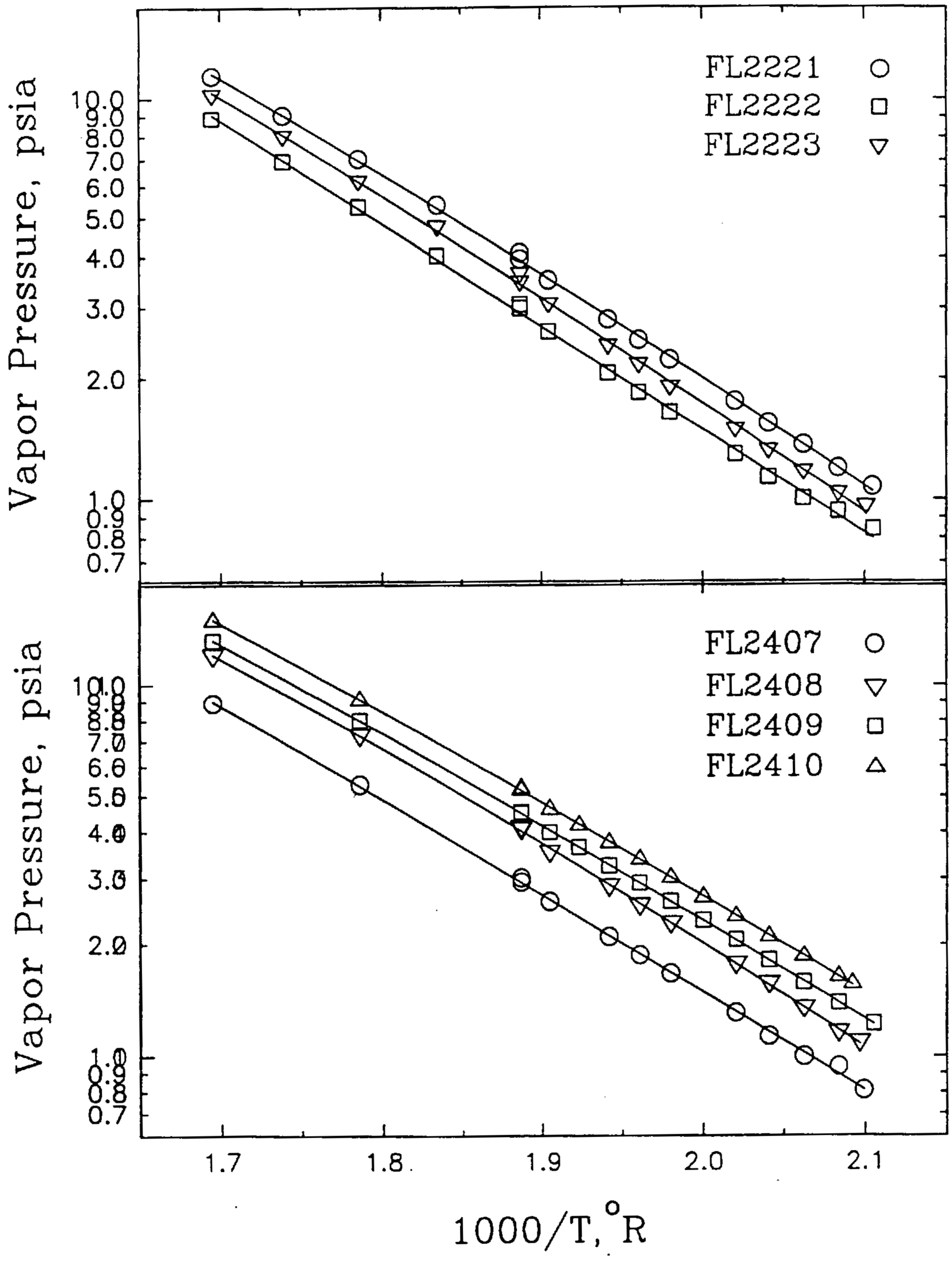

Figure A-1. Clausius-Clapeyron plots for the baseline gasolines showing the effect of temperature on vapor pressure

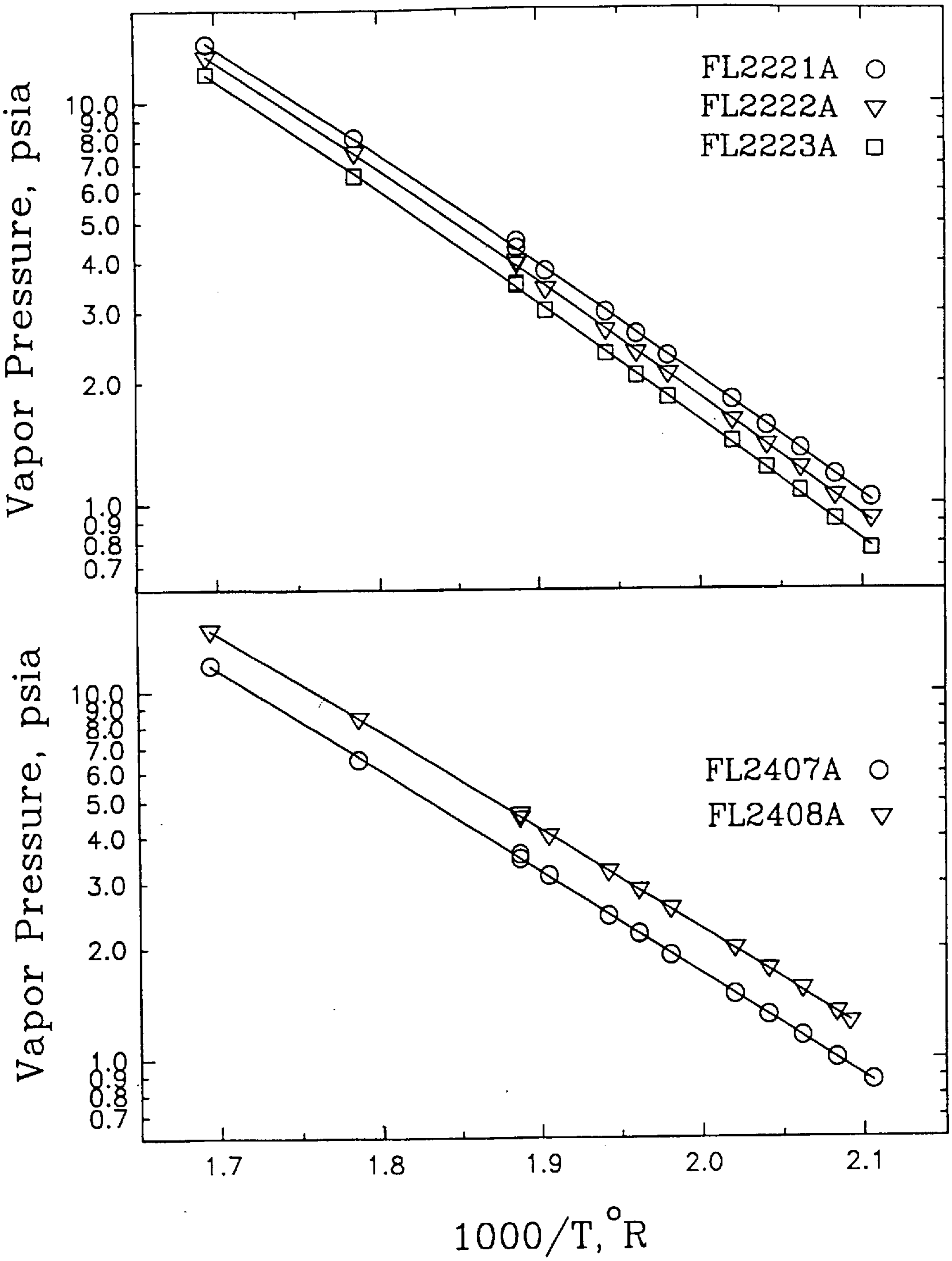

Figure A-2. Clausius-Clapeyron plots for the ethanol-gasoline blends showing the effect of temperature on vapor pressure

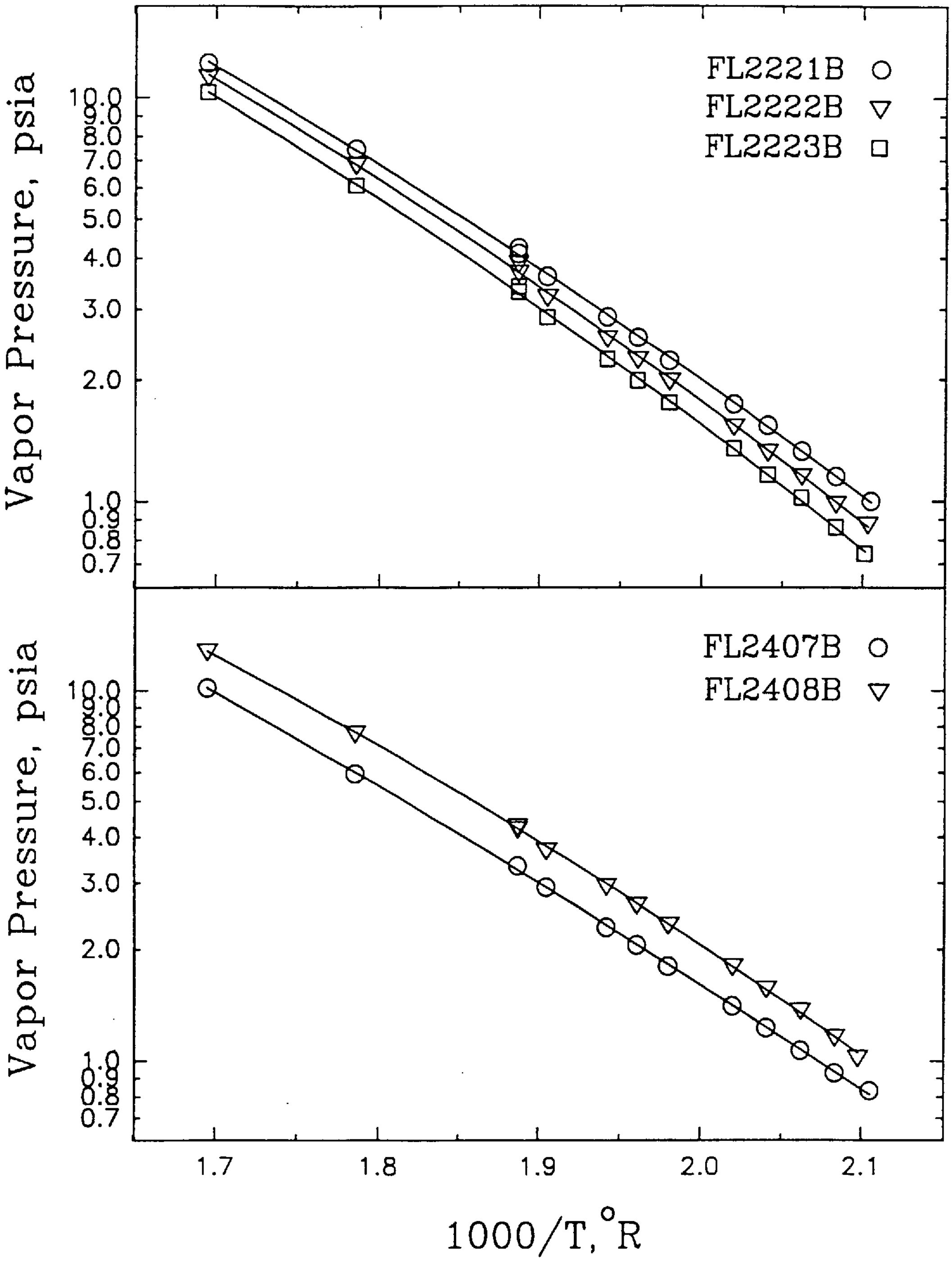

Figure A-3. Clausius-Clapeyron plots for the MTBE-gasoline blends showing the effect of temperature on vapor pressure

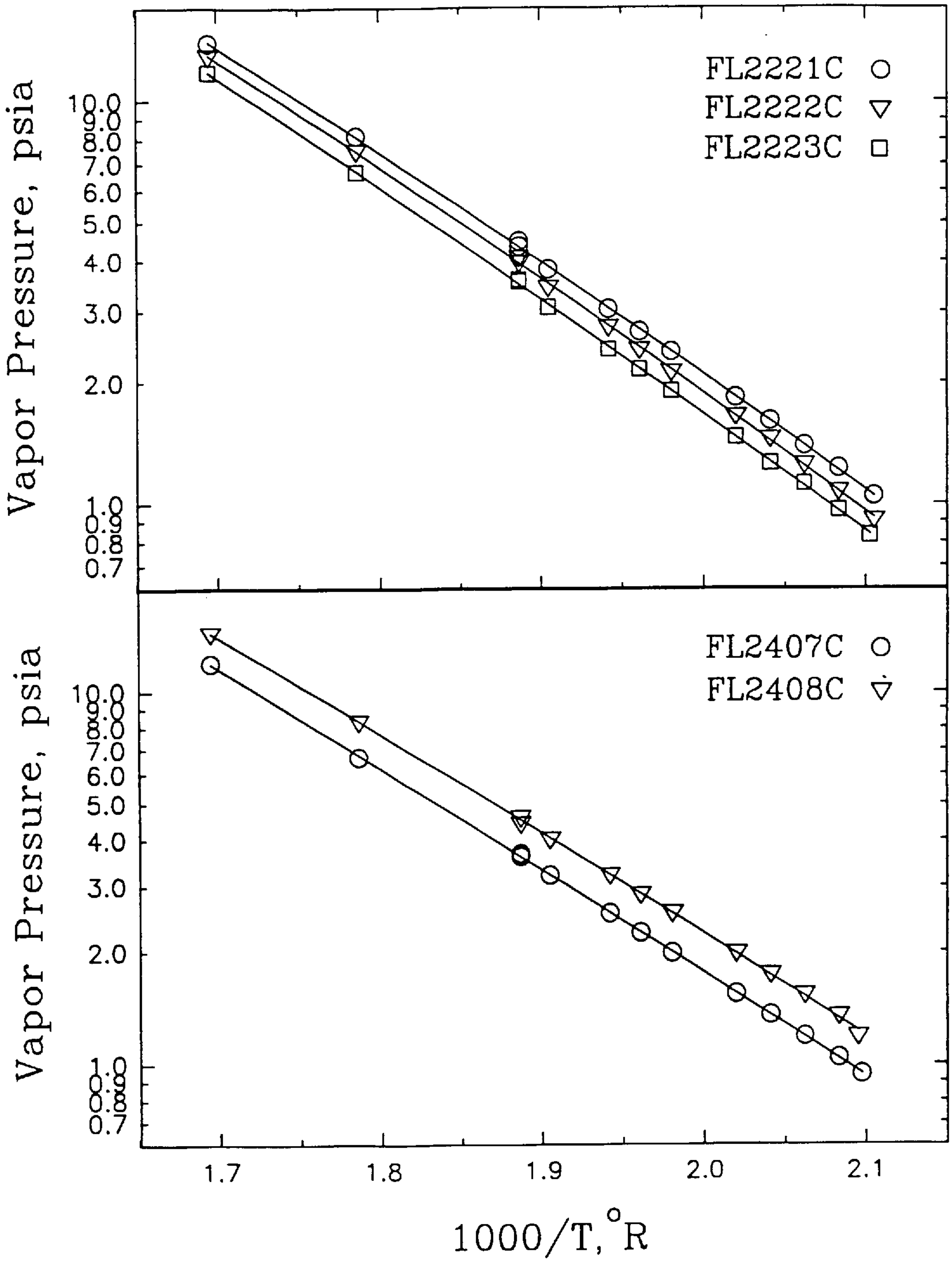

Figure A-4. Clausius-Clapeyron plots for the commingled ethanol/MTBE gasoline blends showing the effect of temperature on vapor pressure

APPENDIX B

Correlations of Vapor Pressure With Temperature and RVP

CORRELATIONS OF VAPOR PRESSURE WITH TEMPERATURE AND RVP

All Test Fuels

Fuel Name	Temperature Deg. R	Measured RVP psia	Measured Vap. Press. psia	Predicted Vap. Press. psia	Residual Vap. Press. psia
FL2221	590.00	7.15	11.42	12.13	-0.71
FL2221	575.00	7.15	9.08	9.41	-0.33
FL2221	560.00	7.15	7.07	7.17	-0.10
FL2221	545.00	7.15	5.41	5.34	0.07
FL2221	530.00	7.15	4.11	3.89	0.22
FL2221	530.00	7.15	3.96	3.89	0.07
FL2221	525.00	7.15	3.51	3.48	0.03
FL2221	515.00	7.15	2.80	2.76	0.04
FL2221	510.00	7.15	2.49	2.45	0.04
FL2221	505.00	7.15	2.22	2.17	0.05
FL2221	495.00	7.15	1.75	1.67	0.08
FL2221	490.00	7.15	1.54	1.46	0.08
FL2221	485.00	7.15	1.36	1.27	0.09
FL2221	480.00	7.15	1.19	1.10	0.09
FL2221	475.10	7.15	1.07	0.96	0.11
FL2222	590.00	6.35	10.24	10.78	-0.54
FL2222	575.00	6.35	8.05	8.36	-0.31
FL2222	560.00	6.35	6.22	6.37	-0.15
FL2222	545.00	6.35	4.78	4.75	0.03
FL2222	530.00	6.35	3.64	3.46	0.18
FL2222	530.00	6.35	3.47	3.46	0.01
FL2222	525.00	6.35	3.06	3.09	-0.03
FL2222	515.00	6.35	2.41	2.46	-0.05
FL2222	510.00	6.35	2.16	2.18	-0.02
FL2222	505.00	6.35	1.90	1.92	-0.02
FL2222	495.00	6.35	1.49	1.49	0.00
FL2222	490.00	6.35	1.32	1.30	0.02
FL2222	485.00	6.35	1.17	1.13	0.04
FL2222	480.00	6.35	1.03	0.98	0.05
FL2222	476.00	6.35	0.96	0.87	0.09
FL2223	590.00	5.44	8.91	9.23	-0.32
FL2223	575.00	5.44	6.95	7.16	-0.21
FL2223	560.00	5.44	5.35	5.45	-0.10
FL2223	545.00	5.44	4.04	4.07	-0.03
FL2223	530.00	5.44	3.05	2.96	0.09
FL2223	530.00	5.44	2.99	2.96	0.03
FL2223	525.00	5.44	2.61	2.65	-0.04
FL2223	515.00	5.44	2.06	2.10	-0.04
FL2223	510.00	5.44	1.84	1.86	-0.02
FL2223	505.00	5.44	1.64	1.65	-0.01
FL2223	495.00	5.44	1.29	1.27	0.02
FL2223	490.00	5.44	1.13	1.11	0.02
FL2223	485.00	5.44	1.00	0.97	0.03
FL2223	480.00	5.44	0.93	0.84	0.09
FL2223	475.00	5.44	0.84	0.73	0.11
FL2407	590.00	5.37	8.91	9.11	-0.20

CORRELATIONS OF VAPOR PRESSURE WITH TEMPERATURE AND RVP (Continued)
All Test Fuels

Fuel Name	Temperature Deg. R	Measured RVP psia	Measured Vap. Press. psia	Predicted Vap. Press. psia	Residual Vap. Press. psia
FL2407	560.00	5.37	5.37	5.38	-0.01
FL2407	530.00	5.37	3.02	2.92	0.10
FL2407	530.00	5.37	2.94	2.92	0.02
FL2407	525.00	5.37	2.61	2.62	-0.01
FL2407	515.00	5.37	2.10	2.08	0.02
FL2407	510.00	5.37	1.87	1.84	0.03
FL2407	505.00	5.37	1.67	1.63	0.04
FL2407	495.00	5.37	1.31	1.26	0.05
FL2407	490.00	5.37	1.13	1.10	0.03
FL2407	485.00	5.37	1.00	0.96	0.04
FL2407	480.00	5.37	0.94	0.83	0.11
FL2407	476.40	5.37	0.81	0.75	0.06
FL2408	590.00	7.29	12.03	12.37	-0.34
FL2408	560.00	7.29	7.29	7.31	-0.02
FL2408	530.00	7.29	4.14	3.97	0.17
FL2408	530.00	7.29	4.08	3.97	0.11
FL2408	525.00	7.29	3.54	3.55	-0.01
FL2408	515.00	7.29	2.87	2.82	0.05
FL2408	510.00	7.29	2.55	2.50	0.05
FL2408	505.00	7.29	2.28	2.21	0.07
FL2408	495.00	7.29	1.77	1.71	0.06
FL2408	490.00	7.29	1.57	1.49	0.08
FL2408	485.00	7.29	1.35	1.30	0.05
FL2408	480.00	7.29	1.16	1.13	0.03
FL2408	477.00	7.29	1.09	1.03	0.06
FL2221A	590.00	8.10	14.02	13.75	0.28
FL2221A	560.00	8.10	8.10	8.12	-0.02
FL2221A	530.00	8.10	4.46	4.41	0.05
FL2221A	530.00	8.10	4.29	4.41	-0.12
FL2221A	525.00	8.10	3.76	3.95	-0.19
FL2221A	515.00	8.10	2.97	3.13	-0.16
FL2221A	510.00	8.10	2.63	2.78	-0.15
FL2221A	505.00	8.10	2.32	2.45	-0.13
FL2221A	495.00	8.10	1.80	1.90	-0.10
FL2221A	490.00	8.10	1.55	1.66	-0.11
FL2221A	485.00	8.10	1.36	1.44	-0.08
FL2221A	480.00	8.10	1.17	1.25	-0.08
FL2221A	475.00	8.10	1.03	1.08	-0.05
FL2221B	590.00	7.51	12.24	12.74	-0.50
FL2221B	560.00	7.51	7.45	7.53	-0.08
FL2221B	530.00	7.51	4.24	4.09	0.15
FL2221B	530.00	7.51	4.10	4.09	0.01
FL2221B	525.00	7.51	3.61	3.66	-0.05
FL2221B	515.00	7.51	2.87	2.90	-0.03
FL2221B	510.00	7.51	2.55	2.57	-0.02
FL2221B	505.00	7.51	2.23	2.27	-0.04

CORRELATIONS OF VAPOR PRESSURE WITH TEMPERATURE AND RVP (Continued)
All Test Fuels

Fuel Name	Temperature Deg. R	Measured RVP psia	Measured Vap. Press. psia	Predicted Vap. Press. psia	Residual Vap. Press. psia
FL2221B	495.00	7.51	1.74	1.76	-0.02
FL2221B	490.00	7.51	1.54	1.54	0.00
FL2221B	485.00	7.51	1.33	1.34	-0.01
FL2221B	480.00	7.51	1.15	1.16	-0.01
FL2221B	475.00	7.51	1.00	1.00	0.00
FL2221C	590.00	8.13	13.96	13.80	0.16
FL2221C	560.00	8.13	8.15	8.15	0.00
FL2221C	530.00	8.13	4.48	4.43	0.05
FL2221C	530.00	8.13	4.35	4.43	-0.08
FL2221C	525.00	8.13	3.81	3.96	-0.15
FL2221C	515.00	8.13	3.03	3.14	-0.11
FL2221C	510.00	8.13	2.67	2.79	-0.12
FL2221C	505.00	8.13	2.38	2.46	-0.08
FL2221C	495.00	8.13	1.83	1.90	-0.07
FL2221C	490.00	8.13	1.60	1.66	-0.06
FL2221C	485.00	8.13	1.39	1.45	-0.06
FL2221C	480.00	8.13	1.22	1.26	-0.04
FL2221C	475.00	8.13	1.04	1.08	-0.04
FL2222A	590.00	7.44	13.01	12.63	0.39
FL2222A	560.00	7.44	7.44	7.46	-0.02
FL2222A	530.00	7.44	3.99	4.05	-0.06
FL2222A	530.00	7.44	3.92	4.05	-0.13
FL2222A	525.00	7.44	3.39	3.63	-0.24
FL2222A	515.00	7.44	2.68	2.88	-0.20
FL2222A	510.00	7.44	2.36	2.55	-0.19
FL2222A	505.00	7.44	2.09	2.25	-0.16
FL2222A	495.00	7.44	1.60	1.74	-0.14
FL2222A	490.00	7.44	1.39	1.52	-0.13
FL2222A	485.00	7.44	1.22	1.33	-0.10
FL2222A	480.00	7.44	1.04	1.15	-0.11
FL2222A	475.00	7.44	0.91	0.99	-0.08
FL2222B	590.00	6.94	11.34	11.78	-0.44
FL2222B	560.00	6.94	6.86	6.96	-0.10
FL2222B	530.00	6.94	3.90	3.78	0.12
FL2222B	530.00	6.94	3.70	3.78	-0.08
FL2222B	525.00	6.94	3.23	3.38	-0.15
FL2222B	515.00	6.94	2.55	2.68	-0.13
FL2222B	510.00	6.94	2.26	2.38	-0.12
FL2222B	505.00	6.94	2.00	2.10	-0.10
FL2222B	495.00	6.94	1.54	1.62	-0.08
FL2222B	490.00	6.94	1.33	1.42	-0.09
FL2222B	485.00	6.94	1.16	1.24	-0.08
FL2222B	480.00	6.94	0.99	1.07	-0.08
FL2222B	475.50	6.94	0.88	0.94	-0.06
FL2222C	590.00	7.51	12.98	12.74	0.24
FL2222C	560.00	7.51	7.51	7.53	-0.02

CORRELATIONS OF VAPOR PRESSURE WITH TEMPERATURE AND RVP (Continued)
All Test Fuels

Fuel Name	Temperature Deg. R	Measured RVP psia	Measured Vap. Press. psia	Predicted Vap. Press. psia	Residual Vap. Press. psia
FL2222C	530.00	7.51	4.08	4.09	-0.01
FL2222C	530.00	7.51	3.97	4.09	-0.12
FL2222C	525.00	7.51	3.44	3.66	-0.22
FL2222C	515.00	7.51	2.74	2.90	-0.16
FL2222C	510.00	7.51	2.41	2.57	-0.16
FL2222C	505.00	7.51	2.12	2.27	-0.15
FL2222C	495.00	7.51	1.65	1.76	-0.11
FL2222C	490.00	7.51	1.45	1.54	-0.09
FL2222C	485.00	7.51	1.25	1.34	-0.09
FL2222C	480.00	7.51	1.07	1.16	-0.09
FL2222C	475.00	7.51	0.91	1.00	-0.09
FL2223A	590.00	6.58	11.80	11.17	0.63
FL2223A	560.00	6.58	6.51	6.60	-0.09
FL2223A	530.00	6.58	3.51	3.58	-0.07
FL2223A	530.00	6.58	3.47	3.58	-0.11
FL2223A	525.00	6.58	3.00	3.21	-0.21
FL2223A	515.00	6.58	2.35	2.54	-0.19
FL2223A	510.00	6.58	2.07	2.26	-0.19
FL2223A	505.00	6.58	1.83	1.99	-0.16
FL2223A	495.00	6.58	1.42	1.54	-0.12
FL2223A	490.00	6.58	1.22	1.35	-0.13
FL2223A	485.00	6.58	1.07	1.17	-0.10
FL2223A	480.00	6.58	0.91	1.02	-0.11
FL2223A	475.00	6.58	0.77	0.88	-0.11
FL2223B	590.00	6.19	10.32	10.50	-0.18
FL2223B	560.00	6.19	6.06	6.21	-0.15
FL2223B	530.00	6.19	3.41	3.37	0.04
FL2223B	530.00	6.19	3.31	3.37	-0.06
FL2223B	525.00	6.19	2.86	3.02	-0.16
FL2223B	515.00	6.19	2.25	2.39	-0.14
FL2223B	510.00	6.19	1.99	2.12	-0.13
FL2223B	505.00	6.19	1.75	1.87	-0.12
FL2223B	495.00	6.19	1.35	1.45	-0.10
FL2223B	490.00	6.19	1.16	1.27	-0.11
FL2223B	485.00	6.19	1.02	1.10	-0.08
FL2223B	480.00	6.19	0.86	0.96	-0.10
FL2223B	475.90	6.19	0.74	0.85	-0.11
FL2223C	590.00	6.68	11.82	11.34	0.48
FL2223C	560.00	6.68	6.64	6.70	-0.06
FL2223C	530.00	6.68	3.59	3.64	-0.05
FL2223C	530.00	6.68	3.55	3.64	-0.09
FL2223C	525.00	6.68	3.06	3.26	-0.19
FL2223C	515.00	6.68	2.41	2.58	-0.17
FL2223C	510.00	6.68	2.15	2.29	-0.14
FL2223C	505.00	6.68	1.90	2.02	-0.12
FL2223C	495.00	6.68	1.46	1.56	-0.10

CORRELATIONS OF VAPOR PRESSURE WITH TEMPERATURE AND RVP (Continued)
All Test Fuels

Fuel Name	Temperature Deg. R	Measured RVP psia	Measured Vap. Press. psia	Predicted Vap. Press. psia	Residual Vap. Press. psia
FL2223C	490.00	6.68	1.26	1.37	-0.11
FL2223C	485.00	6.68	1.12	1.19	-0.07
FL2223C	480.00	6.68	0.96	1.03	-0.07
FL2223C	475.60	6.68	0.83	0.91	-0.08
FL2407A	590.00	6.55	11.84	11.11	0.73
FL2407A	560.00	6.55	6.52	6.57	-0.05
FL2407A	530.00	6.55	3.50	3.57	-0.07
FL2407A	530.00	6.55	3.60	3.57	0.03
FL2407A	525.00	6.55	3.15	3.19	-0.04
FL2407A	515.00	6.55	2.44	2.53	-0.09
FL2407A	510.00	6.55	2.18	2.25	-0.07
FL2407A	505.00	6.55	1.91	1.98	-0.07
FL2407A	495.00	6.55	1.49	1.53	-0.04
FL2407A	490.00	6.55	1.31	1.34	-0.03
FL2407A	485.00	6.55	1.15	1.17	-0.02
FL2407A	480.00	6.55	1.00	1.01	-0.01
FL2407A	475.00	6.55	0.87	0.87	0.00
FL2407B	590.00	6.07	10.15	10.30	-0.15
FL2407B	560.00	6.07	5.93	6.09	-0.16
FL2407B	530.00	6.07	3.35	3.31	0.04
FL2407B	530.00	6.07	3.35	3.31	0.04
FL2407B	525.00	6.07	2.93	2.96	-0.03
FL2407B	515.00	6.07	2.29	2.35	-0.06
FL2407B	510.00	6.07	2.05	2.08	-0.03
FL2407B	505.00	6.07	1.80	1.84	-0.04
FL2407B	495.00	6.07	1.41	1.42	-0.01
FL2407B	490.00	6.07	1.23	1.24	-0.01
FL2407B	485.00	6.07	1.07	1.08	-0.01
FL2407B	480.00	6.07	0.93	0.94	-0.01
FL2407B	475.00	6.07	0.83	0.81	0.02
FL2407C	590.00	6.72	11.92	11.40	0.52
FL2407C	560.00	6.72	6.67	6.74	-0.07
FL2407C	530.00	6.72	3.61	3.66	-0.05
FL2407C	530.00	6.72	3.68	3.66	0.02
FL2407C	525.00	6.72	3.21	3.27	-0.06
FL2407C	515.00	6.72	2.54	2.60	-0.06
FL2407C	510.00	6.72	2.25	2.30	-0.05
FL2407C	505.00	6.72	1.99	2.04	-0.05
FL2407C	495.00	6.72	1.55	1.57	-0.02
FL2407C	490.00	6.72	1.36	1.37	-0.01
FL2407C	485.00	6.72	1.19	1.20	-0.01
FL2407C	480.00	6.72	1.04	1.04	0.00
FL2407C	476.80	6.72	0.94	0.95	-0.01
FL2408A	590.00	8.33	14.72	14.14	0.59
FL2408A	560.00	8.33	8.45	8.35	0.10
FL2408A	530.00	8.33	4.52	4.54	-0.02

CORRELATIONS OF VAPOR PRESSURE WITH TEMPERATURE AND RVP (Continued)

All Test Fuels

Fuel Name	Temperature Deg. R	Measured RVP psia	Measured Vap. Press. psia	Predicted Vap. Press. psia	Residual Vap. Press. psia
FL2408A	530.00	8.33	4.63	4.54	0.09
FL2408A	525.00	8.33	4.03	4.06	-0.03
FL2408A	515.00	8.33	3.22	3.22	0.00
FL2408A	510.00	8.33	2.87	2.86	0.01
FL2408A	505.00	8.33	2.55	2.52	0.03
FL2408A	495.00	8.33	1.99	1.95	0.04
FL2408A	490.00	8.33	1.75	1.70	0.05
FL2408A	485.00	8.33	1.54	1.48	0.06
FL2408A	480.00	8.33	1.33	1.29	0.04
FL2408A	478.20	8.33	1.25	1.22	0.03
FL2408B	590.00	7.71	12.82	13.08	-0.26
FL2408B	560.00	7.71	7.71	7.73	-0.02
FL2408B	530.00	7.71	4.31	4.20	0.11
FL2408B	530.00	7.71	4.24	4.20	0.04
FL2408B	525.00	7.71	3.71	3.76	-0.05
FL2408B	515.00	7.71	2.97	2.98	-0.01
FL2408B	510.00	7.71	2.64	2.64	0.00
FL2408B	505.00	7.71	2.34	2.34	0.01
FL2408B	495.00	7.71	1.81	1.80	0.01
FL2408B	490.00	7.71	1.58	1.58	0.00
FL2408B	485.00	7.71	1.38	1.37	0.01
FL2408B	480.00	7.71	1.17	1.19	-0.02
FL2408B	476.70	7.71	1.03	1.08	-0.05
FL2408C	590.00	8.24	14.42	13.98	0.44
FL2408C	560.00	8.24	8.34	8.26	0.08
FL2408C	530.00	8.24	4.43	4.49	-0.06
FL2408C	530.00	8.24	4.61	4.49	0.12
FL2408C	525.00	8.24	4.02	4.02	0.00
FL2408C	515.00	8.24	3.22	3.19	0.03
FL2408C	510.00	8.24	2.86	2.82	0.04
FL2408C	505.00	8.24	2.55	2.50	0.05
FL2408C	495.00	8.24	1.99	1.93	0.06
FL2408C	490.00	8.24	1.75	1.69	0.06
FL2408C	485.00	8.24	1.54	1.47	0.07
FL2408C	480.00	8.24	1.35	1.27	0.08
FL2408C	477.30	8.24	1.19	1.18	0.01
FL2409	475.00	7.89	1.22	1.05	0.17
FL2409	480.00	7.89	1.39	1.22	0.17
FL2409	485.00	7.89	1.58	1.41	0.17
FL2409	490.00	7.89	1.81	1.61	0.20
FL2409	495.00	7.89	2.06	1.85	0.21
FL2409	500.00	7.89	2.32	2.10	0.22
FL2409	505.00	7.89	2.61	2.39	0.22
FL2409	510.00	7.89	2.92	2.70	0.22
FL2409	515.00	7.89	3.25	3.05	0.20
FL2409	520.00	7.89	3.64	3.43	0.21

CORRELATIONS OF VAPOR PRESSURE WITH TEMPERATURE AND RVP (Continued)
All Test Fuels

Fuel Name	Temperature Deg. R	Measured RVP psia	Measured Vap. Press. psia	Predicted Vap. Press. psia	Residual Vap. Press. psia
FL2409	525.00	7.89	4.00	3.84	0.16
FL2409	530.00	7.89	4.54	4.30	0.24
FL2409	530.00	7.89	4.51	4.30	0.21
FL2409	560.00	7.89	8.01	7.91	0.10
FL2409	590.00	7.89	13.20	13.39	-0.19
FL2410	478.30	8.94	1.57	1.31	0.26
FL2410	480.00	8.94	1.64	1.38	0.26
FL2410	485.00	8.94	1.86	1.59	0.27
FL2410	490.00	8.94	2.10	1.83	0.27
FL2410	495.00	8.94	2.38	2.09	0.29
FL2410	500.00	8.94	2.68	2.38	0.30
FL2410	505.00	8.94	3.02	2.71	0.31
FL2410	510.00	8.94	3.39	3.06	0.33
FL2410	515.00	8.94	3.76	3.46	0.30
FL2410	520.00	8.94	4.19	3.89	0.30
FL2410	525.00	8.94	4.63	4.36	0.27
FL2410	530.00	8.94	5.21	4.87	0.34
FL2410	530.00	8.94	5.27	4.87	0.40
FL2410	560.00	8.94	9.13	8.96	0.17
FL2410	590.00	8.94	14.99	15.17	-0.18

CORRELATIONS OF VAPOR PRESSURE WITH TEMPERATURE AND RVP
Baseline Gasolines

Fuel Name	Temperature Deg. R	Measured RVP psia	Measured Vap. Press. psia	Predicted Vap. Press. psia	Residual Vap. Press. psia
FL2221	590.00	7.15	11.42	11.76	-0.34
FL2221	575.00	7.15	9.08	9.25	-0.17
FL2221	560.00	7.15	7.07	7.15	-0.08
FL2221	545.00	7.15	5.41	5.41	0.00
FL2221	530.00	7.15	4.11	4.01	0.10
FL2221	530.00	7.15	3.96	4.01	-0.05
FL2221	525.00	7.15	3.51	3.61	-0.10
FL2221	515.00	7.15	2.80	2.90	-0.10
FL2221	510.00	7.15	2.49	2.59	-0.10
FL2221	505.00	7.15	2.22	2.30	-0.08
FL2221	495.00	7.15	1.75	1.80	-0.05
FL2221	490.00	7.15	1.54	1.59	-0.05
FL2221	485.00	7.15	1.36	1.39	-0.03
FL2221	480.00	7.15	1.19	1.22	-0.03
FL2221	475.10	7.15	1.07	1.06	0.01
FL2222	590.00	6.35	10.24	10.44	-0.20
FL2222	575.00	6.35	8.05	8.21	-0.16
FL2222	560.00	6.35	6.22	6.35	-0.13
FL2222	545.00	6.35	4.78	4.81	-0.03
FL2222	530.00	6.35	3.64	3.56	0.08
FL2222	530.00	6.35	3.47	3.56	-0.09
FL2222	525.00	6.35	3.06	3.21	-0.15
FL2222	515.00	6.35	2.41	2.58	-0.17
FL2222	510.00	6.35	2.16	2.30	-0.14
FL2222	505.00	6.35	1.90	2.05	-0.15
FL2222	495.00	6.35	1.49	1.60	-0.11
FL2222	490.00	6.35	1.32	1.41	-0.09
FL2222	485.00	6.35	1.17	1.24	-0.07
FL2222	480.00	6.35	1.03	1.08	-0.05
FL2222	476.00	6.35	0.96	0.97	-0.01
FL2223	590.00	5.44	8.91	8.95	-0.04
FL2223	575.00	5.44	6.95	7.04	-0.09
FL2223	560.00	5.44	5.35	5.44	-0.09
FL2223	545.00	5.44	4.04	4.12	-0.08
FL2223	530.00	5.44	3.05	3.05	0.00
FL2223	530.00	5.44	2.99	3.05	-0.06
FL2223	525.00	5.44	2.61	2.75	-0.14
FL2223	515.00	5.44	2.06	2.21	-0.15
FL2223	510.00	5.44	1.84	1.97	-0.13
FL2223	505.00	5.44	1.64	1.75	-0.11
FL2223	495.00	5.44	1.29	1.37	-0.08
FL2223	490.00	5.44	1.13	1.21	-0.08
FL2223	485.00	5.44	1.00	1.06	-0.06
FL2223	480.00	5.44	0.93	0.93	0.00
FL2223	475.00	5.44	0.84	0.81	0.03
FL2407	590.00	5.37	8.91	8.83	0.08

CORRELATIONS OF VAPOR PRESSURE WITH TEMPERATURE AND RVP (Continued)
Baseline Gasolines

Fuel Name	Temperature Deg. R	Measured RVP psia	Measured Vap. Press. psia	Predicted Vap. Press. psia	Residual Vap. Press. psia
FL2407	560.00	5.37	5.37	5.37	0.00
FL2407	530.00	5.37	3.02	3.01	0.01
FL2407	530.00	5.37	2.94	3.01	-0.07
FL2407	525.00	5.37	2.61	2.71	-0.10
FL2407	515.00	5.37	2.10	2.18	-0.08
FL2407	510.00	5.37	1.87	1.94	-0.07
FL2407	505.00	5.37	1.67	1.73	-0.06
FL2407	495.00	5.37	1.31	1.36	-0.05
FL2407	490.00	5.37	1.13	1.19	-0.06
FL2407	485.00	5.37	1.00	1.05	-0.05
FL2407	480.00	5.37	0.94	0.92	0.02
FL2407	476.40	5.37	0.81	0.83	-0.02
FL2408	590.00	7.29	12.03	11.99	0.04
FL2408	560.00	7.29	7.29	7.28	0.01
FL2408	530.00	7.29	4.14	4.09	0.05
FL2408	530.00	7.29	4.08	4.09	-0.01
FL2408	525.00	7.29	3.54	3.68	-0.14
FL2408	515.00	7.29	2.87	2.96	-0.09
FL2408	510.00	7.29	2.55	2.64	-0.09
FL2408	505.00	7.29	2.28	-2.35	0.07
FL2408	495.00	7.29	1.77	-1.84	0.07
FL2408	490.00	7.29	1.57	-1.62	0.05
FL2408	485.00	7.29	1.35	-1.42	0.07
FL2408	480.00	7.29	1.16	-1.24	0.08
FL2408	477.00	7.29	1.09	-1.14	0.05
FL2409	475.00	7.89	1.22	1.17	0.05
FL2409	480.00	7.89	1.39	1.34	0.05
FL2409	485.00	7.89	1.58	1.54	0.04
FL2409	490.00	7.89	1.81	1.75	0.06
FL2409	495.00	7.89	2.06	1.99	0.07
FL2409	500.00	7.89	2.32	2.25	0.07
FL2409	505.00	7.89	2.61	2.54	0.07
FL2409	510.00	7.89	2.92	2.86	0.06
FL2409	515.00	7.89	3.25	3.20	0.05
FL2409	520.00	7.89	3.64	3.58	0.06
FL2409	525.00	7.89	4.00	3.98	0.02
FL2409	530.00	7.89	4.54	4.43	0.11
FL2409	530.00	7.89	4.51	4.43	0.08
FL2409	560.00	7.89	8.01	7.88	0.13
FL2409	590.00	7.89	13.20	12.98	0.23
FL2410	478.30	8.94	1.57	1.45	0.12
FL2410	480.00	8.94	1.64	1.52	0.12
FL2410	485.00	8.94	1.86	1.74	0.12
FL2410	490.00	8.94	2.10	1.99	0.11
FL2410	495.00	8.94	2.38	2.26	0.12
FL2410	500.00	8.94	2.68	2.55	0.13

CORRELATIONS OF VAPOR PRESSURE WITH TEMPERATURE AND RVP (Continued)
Baseline Gasolines

Fuel Name	Temperature Deg. R	Measured RVP psia	Measured Vap. Press. psia	Predicted Vap. Press. psia	Residual Vap. Press. psia
FL2410	505.00	8.94	3.02	2.88	0.14
FL2410	510.00	8.94	3.39	3.24	0.15
FL2410	515.00	8.94	3.76	3.63	0.13
FL2410	520.00	8.94	4.19	4.05	0.14
FL2410	525.00	8.94	4.63	4.51	0.12
FL2410	530.00	8.94	5.21	5.02	0.19
FL2410	530.00	8.94	5.27	5.02	0.25
FL2410	560.00	8.94	9.13	8.93	0.20
FL2410	590.00	8.94	14.99	14.70	0.29

CORRELATIONS OF VAPOR PRESSURE WITH TEMPERATURE AND RVP
Ethanol/Gasoline Blends

Fuel Name	Temperature Deg. R	Measured RVP psia	Measured Vap. Press. psia	Predicted Vap. Press. psia	Residual Vap. Press. psia
FL2221A	590.00	8.10	14.02	14.29	-0.27
FL2221A	560.00	8.10	8.10	8.15	-0.05
FL2221A	530.00	8.10	4.46	4.31	0.15
FL2221A	530.00	8.10	4.29	4.31	-0.02
FL2221A	525.00	8.10	3.76	3.84	-0.08
FL2221A	515.00	8.10	2.97	3.03	-0.06
FL2221A	510.00	8.10	2.63	2.68	-0.05
FL2221A	505.00	8.10	2.32	2.36	-0.04
FL2221A	495.00	8.10	1.80	1.82	-0.02
FL2221A	490.00	8.10	1.55	1.59	-0.04
FL2221A	485.00	8.10	1.36	1.38	-0.02
FL2221A	480.00	8.10	1.17	1.20	-0.03
FL2221A	475.00	8.10	1.03	1.04	-0.01
FL2222A	590.00	7.44	13.01	13.13	-0.12
FL2222A	560.00	7.44	7.44	7.49	-0.05
FL2222A	530.00	7.44	3.99	3.96	0.03
FL2222A	530.00	7.44	3.92	3.96	-0.04
FL2222A	525.00	7.44	3.39	3.53	-0.14
FL2222A	515.00	7.44	2.68	2.78	-0.10
FL2222A	510.00	7.44	2.36	2.46	-0.10
FL2222A	505.00	7.44	2.09	2.17	-0.08
FL2222A	495.00	7.44	1.60	1.67	-0.07
FL2222A	490.00	7.44	1.39	1.46	-0.07
FL2222A	485.00	7.44	1.22	1.27	-0.05
FL2222A	480.00	7.44	1.04	1.10	-0.06
FL2222A	475.00	7.44	0.91	0.95	-0.04
FL2223A	590.00	6.58	11.80	11.61	0.19
FL2223A	560.00	6.58	6.51	6.62	-0.11
FL2223A	530.00	6.58	3.51	3.50	0.01
FL2223A	530.00	6.58	3.47	3.50	-0.03
FL2223A	525.00	6.58	3.00	3.12	-0.12
FL2223A	515.00	6.58	2.35	2.46	-0.11
FL2223A	510.00	6.58	2.07	2.17	-0.10
FL2223A	505.00	6.58	1.83	1.92	-0.09
FL2223A	495.00	6.58	1.42	1.48	-0.06
FL2223A	490.00	6.58	1.22	1.29	-0.07
FL2223A	485.00	6.58	1.07	1.12	-0.05
FL2223A	480.00	6.58	0.91	0.97	-0.06
FL2223A	475.00	6.58	0.77	0.84	-0.07
FL2407A	590.00	6.55	11.84	11.56	0.28
FL2407A	560.00	6.55	6.52	6.59	-0.07
FL2407A	530.00	6.55	3.50	3.48	0.02
FL2407A	530.00	6.55	3.60	3.48	0.12
FL2407A	525.00	6.55	3.15	3.10	0.05
FL2407A	515.00	6.55	2.44	2.45	-0.01
FL2407A	510.00	6.55	2.18	2.16	0.02

CORRELATIONS OF VAPOR PRESSURE WITH TEMPERATURE AND RVP (Continued)
Ethanol/Gasoline Blends

Fuel Name	Temperature Deg. R	Measured RVP psia	Measured Vap. Press. psia	Predicted Vap. Press. psia	Residual Vap. Press. psia
FL2407A	505.00	6.55	1.91	1.91	0.00
FL2407A	495.00	6.55	1.49	1.47	0.02
FL2407A	490.00	6.55	1.31	1.28	0.03
FL2407A	485.00	6.55	1.15	1.12	0.03
FL2407A	480.00	6.55	1.00	0.97	0.03
FL2407A	475.00	6.55	0.87	0.84	0.03
FL2408A	590.00	8.33	14.72	14.70	0.02
FL2408A	560.00	8.33	8.45	8.38	0.07
FL2408A	530.00	8.33	4.52	4.43	0.09
FL2408A	530.00	8.33	4.63	4.43	0.20
FL2408A	525.00	8.33	4.03	3.95	0.08
FL2408A	515.00	8.33	3.22	3.11	0.11
FL2408A	510.00	8.33	2.87	2.75	0.12
FL2408A	505.00	8.33	2.55	2.43	0.12
FL2408A	495.00	8.33	1.99	1.87	0.12
FL2408A	490.00	8.33	1.75	1.63	0.12
FL2408A	485.00	8.33	1.54	1.42	0.12
FL2408A	480.00	8.33	1.33	1.23	0.10
FL2408A	478.20	8.33	1.25	1.17	0.08

CORRELATIONS OF VAPOR PRESSURE WITH TEMPERATURE AND RVP
MTBE/Gasoline Blends

Fuel Name	Temperature Deg. R	Measured RVP psia	Measured Vap. Press. psia	Predicted Vap. Press. psia	Residual Vap. Press. psia
FL2221B	590.00	7.51	12.24	12.40	-0.16
FL2221B	560.00	7.51	7.45	7.45	0.00
FL2221B	530.00	7.51	4.24	4.06	0.18
FL2221B	530.00	7.51	4.10	4.06	0.04
FL2221B	525.00	7.51	3.61	3.63	-0.02
FL2221B	515.00	7.51	2.87	2.87	0.00
FL2221B	510.00	7.51	2.55	2.54	0.01
FL2221B	505.00	7.51	2.23	2.24	-0.01
FL2221B	495.00	7.51	1.74	1.71	0.03
FL2221B	490.00	7.51	1.54	1.49	0.05
FL2221B	485.00	7.51	1.33	1.29	0.04
FL2221B	480.00	7.51	1.15	1.11	0.04
FL2221B	475.00	7.51	1.00	0.95	0.05
FL2222B	590.00	6.94	11.34	11.46	-0.12
FL2222B	560.00	6.94	6.86	6.89	-0.03
FL2222B	530.00	6.94	3.90	3.76	0.14
FL2222B	530.00	6.94	3.70	3.76	-0.06
FL2222B	525.00	6.94	3.23	3.36	-0.13
FL2222B	515.00	6.94	2.55	2.65	-0.10
FL2222B	510.00	6.94	2.26	2.35	-0.09
FL2222B	505.00	6.94	2.00	2.07	-0.07
FL2222B	495.00	6.94	1.54	1.58	-0.04
FL2222B	490.00	6.94	1.33	1.37	-0.04
FL2222B	485.00	6.94	1.16	1.19	-0.03
FL2222B	480.00	6.94	0.99	1.02	-0.03
FL2222B	475.50	6.94	0.88	0.89	-0.01
FL2223B	590.00	6.19	10.32	10.22	0.10
FL2223B	560.00	6.19	6.06	6.14	-0.08
FL2223B	530.00	6.19	3.41	3.35	0.06
FL2223B	530.00	6.19	3.31	3.35	-0.04
FL2223B	525.00	6.19	2.86	2.99	-0.13
FL2223B	515.00	6.19	2.25	2.37	-0.12
FL2223B	510.00	6.19	1.99	2.09	-0.10
FL2223B	505.00	6.19	1.75	1.84	-0.09
FL2223B	495.00	6.19	1.35	1.41	-0.06
FL2223B	490.00	6.19	1.16	1.23	-0.07
FL2223B	485.00	6.19	1.02	1.06	-0.04
FL2223B	480.00	6.19	0.86	0.91	-0.05
FL2223B	475.90	6.19	0.74	0.80	-0.06
FL2407B	590.00	6.07	10.15	10.02	0.13
FL2407B	560.00	6.07	5.93	6.02	-0.09
FL2407B	530.00	6.07	3.35	3.29	0.06
FL2407B	530.00	6.07	3.35	3.29	0.06
FL2407B	525.00	6.07	2.93	2.94	-0.01
FL2407B	515.00	6.07	2.29	2.32	-0.03
FL2407B	510.00	6.07	2.05	2.05	0.00

CORRELATIONS OF VAPOR PRESSURE WITH TEMPERATURE AND RVP (Continued)
MTBE/Gasoline Blends

Fuel Name	Temperature Deg. R	Measured RVP psia	Measured Vap. Press. psia	Predicted Vap. Press. psia	Residual Vap. Press. psia
FL2407B	505.00	6.07	1.80	1.81	-0.01
FL2407B	495.00	6.07	1.41	1.38	0.03
FL2407B	490.00	6.07	1.23	1.20	0.03
FL2407B	485.00	6.07	1.07	1.04	0.03
FL2407B	480.00	6.07	0.93	0.90	0.03
FL2407B	475.00	6.07	0.83	0.77	0.06
FL2408B	590.00	7.71	12.82	12.73	0.09
FL2408B	560.00	7.71	7.71	7.65	0.06
FL2408B	530.00	7.71	4.31	4.17	0.14
FL2408B	530.00	7.71	4.24	4.17	0.07
FL2408B	525.00	7.71	3.71	3.73	-0.02
FL2408B	515.00	7.71	2.97	2.95	0.02
FL2408B	510.00	7.71	2.64	2.61	0.03
FL2408B	505.00	7.71	2.34	2.29	0.05
FL2408B	495.00	7.71	1.81	1.76	0.05
FL2408B	490.00	7.71	1.58	1.53	0.05
FL2408B	485.00	7.71	1.38	1.32	0.06
FL2408B	480.00	7.71	1.17	1.14	0.03

CORRELATIONS OF VAPOR PRESSURE WITH TEMPERATURE AND RVP
Ethanol/MTBE/Gasoline Blends

Fuel Name	Temperature Deg. R	Measured RVP psia	Measured Vap. Press. psia	Predicted Vap. Press. psia	Residual Vap. Press. psia
FL2221C	590.00	8.13	13.96	14.18	-0.22
FL2221C	560.00	8.13	8.15	8.17	-0.01
FL2221C	530.00	8.13	4.48	4.35	0.13
FL2221C	530.00	8.13	4.35	4.35	0.00
FL2221C	525.00	8.13	3.81	3.88	-0.07
FL2221C	515.00	8.13	3.03	3.07	-0.04
FL2221C	510.00	8.13	2.67	2.72	-0.05
FL2221C	505.00	8.13	2.38	2.40	-0.02
FL2221C	495.00	8.13	1.83	1.85	-0.02
FL2221C	490.00	8.13	1.60	1.62	-0.02
FL2221C	485.00	8.13	1.39	1.41	-0.02
FL2221C	480.00	8.13	1.22	1.22	0.00
FL2221C	475.00	8.13	1.04	1.06	-0.02
FL2222C	590.00	7.51	12.98	13.10	-0.12
FL2222C	560.00	7.51	7.51	7.54	-0.03
FL2222C	530.00	7.51	4.08	4.02	0.06
FL2222C	530.00	7.51	3.97	4.02	-0.05
FL2222C	525.00	7.51	3.44	3.59	-0.15
FL2222C	515.00	7.51	2.74	2.83	-0.09
FL2222C	510.00	7.51	2.41	2.51	-0.10
FL2222C	505.00	7.51	2.12	2.21	-0.09
FL2222C	495.00	7.51	1.65	1.71	-0.06
FL2222C	490.00	7.51	1.45	1.49	-0.04
FL2222C	485.00	7.51	1.25	1.30	-0.05
FL2222C	480.00	7.51	1.07	1.13	-0.06
FL2222C	475.00	7.51	0.91	0.98	-0.07
FL2223C	590.00	6.68	11.82	11.65	0.17
FL2223C	560.00	6.68	6.64	6.71	-0.07
FL2223C	530.00	6.68	3.59	3.57	0.02
FL2223C	530.00	6.68	3.55	3.57	-0.02
FL2223C	525.00	6.68	3.06	3.19	-0.13
FL2223C	515.00	6.68	2.41	2.52	-0.11
FL2223C	510.00	6.68	2.15	2.23	-0.08
FL2223C	505.00	6.68	1.90	1.97	-0.07
FL2223C	495.00	6.68	1.46	1.52	-0.06
FL2223C	490.00	6.68	1.26	1.33	-0.07
FL2223C	485.00	6.68	1.12	1.16	-0.04
FL2223C	480.00	6.68	0.96	1.00	-0.04
FL2223C	475.60	6.68	0.83	0.88	-0.05
FL2407C	590.00	6.72	11.92	11.72	0.20
FL2407C	560.00	6.72	6.67	6.75	-0.08
FL2407C	530.00	6.72	3.61	3.60	0.01
FL2407C	530.00	6.72	3.68	3.60	0.08
FL2407C	525.00	6.72	3.21	3.21	0.00
FL2407C	515.00	6.72	2.54	2.54	0.00
FL2407C	510.00	6.72	2.25	2.24	0.01

CORRELATIONS OF VAPOR PRESSURE WITH TEMPERATURE AND RVP (Continued)
Ethanol/MTBE/Gasoline Blends

Fuel Name	Temperature Deg. R	Measured RVP psia	Measured Vap. Press. psia	Predicted Vap. Press. psia	Residual Vap. Press. psia
FL2407C	505.00	6.72	1.99	1.98	0.01
FL2407C	495.00	6.72	1.55	1.53	0.02
FL2407C	490.00	6.72	1.36	1.34	0.02
FL2407C	485.00	6.72	1.19	1.16	0.03
FL2407C	480.00	6.72	1.04	1.01	0.03
FL2407C	476.80	6.72	0.94	0.92	0.02
FL2408C	590.00	8.24	14.42	14.37	0.05
FL2408C	560.00	8.24	8.34	8.28	0.06
FL2408C	530.00	8.24	4.43	4.41	0.02
FL2408C	530.00	8.24	4.61	4.41	0.20
FL2408C	525.00	8.24	4.02	3.93	0.09
FL2408C	515.00	8.24	3.22	3.11	0.11
FL2408C	510.00	8.24	2.86	2.75	0.11
FL2408C	505.00	8.24	2.55	2.43	0.12
FL2408C	495.00	8.24	1.99	1.87	0.12
FL2408C	490.00	8.24	1.75	1.64	0.11
FL2408C	485.00	8.24	1.54	1.43	0.11
FL2408C	480.00	8.24	1.35	1.24	0.11
FL2408C	477.30	8.24	1.19	1.14	0.05

APPENDIX C

Temperature Limits of Flammability Data

Table C-1. Temperature Limits of Flammability: All Data				
Fuel Name	Upper Limit Trials		Lower Limit Trials	
	Ignition Description	Temperature °F (°C)	Ignition Description	Temperature °F (°C)
FL2221	Negative	16.2 (-8.8)	Negative	-49.0 (-45.0)
FL2221	Negative	18.5 (-7.5)	Negative	-45.6 (-43.1)
FL2221	Negative	16.5 (-8.6)	Negative	-44.0 (-42.2)
FL2221	Positive (W)*	15.6 (-9.1)	Negative	-42.3 (-41.3)
FL2221	Positive (M)†	13.3 (-10.4)	Positive (W)	-40.7 (-40.4)
FL2221	Positive (S)‡	10.0 (-12.2)	Positive (M)	-41.4 (-40.8)
FL2221	---	---	Positive (M)	-39.6 (-39.8)
FL2221A	Positive (W)	12.2 (-11.0)	Positive (M)	-22.0 (-30.0)
FL2221A	Negative	21.6 (-5.8)	Negative	-38.0 (-38.9)
FL2221A	Negative	17.2 (-8.2)	Negative	-33.9 (-36.6)
FL2221A	Negative	11.8 (-11.2)	Positive (M)	-30.3 (-34.6)
FL2221A	Positive (M)	9.0 (-12.8)	Negative	-32.0 (-35.6)
FL2221A	Positive (M)	6.8 (-14.0)	---	---
FL2221A	Positive (M)	4.3 (-15.4)	---	---
FL2221A	Negative	13.6 (-10.2)	---	---
FL2221B	Negative	14.5 (-9.7)	Negative	-36.9 (-38.3)
FL2221B	Positive (M)	12.0 (-11.1)	Negative	-34.1 (-36.7)
FL2221B	Positive (M)	12.7 (-10.7)	Positive (S)	-32.4 (-35.8)
FL2221B	Negative	14.0 (-10.0)	Positive (S)	-27.6 (-33.1)
FL2221B	---	---	Positive (W)	-33.5 (-36.4)
FL2221C	Negative	13.3 (-10.4)	Positive (S)	-17.3 (-27.4)
FL2221C	Negative	9.1 (-12.7)	Positive (S)	-29.6 (-34.2)
FL2221C	Positive (M)	4.8 (-15.1)	Negative	-31.4 (-35.2)

* W = Weak explosion
† M = Medium explosion
‡ S = Strong explosion

Table C-1 (cont'd). Temperature Limits of Flammability: All Data

Fuel Name	Upper Limit Trials		Lower Limit Trials	
	Ignition Description	Temperature °F (°C)	Ignition Description	Temperature °F (°C)
FL221C	Positive (M)	5.9 (-14.5)	Positive (W)	-30.6 (-34.8)
FL221C	Negative	7.3 (-13.7)	---	---
FL2222	Positive (M)	13.6 (-10.2)	Negative	-35.7 (-37.6)
FL2222	Positive (M)	15.3 (-9.3)	Negative	-33.3 (-36.3)
FL2222	Negative	17.4 (-8.1)	Negative	-31.4 (-35.2)
FL2222	Negative	18.7 (-7.4)	Positive (W)	-30.5 (-34.7)
FL2222	Negative	18.0 (-7.8)	Positive (S)	-28.8 (-33.8)
FL2222	Positive (W)	17.1 (-8.3)	Positive (W)	-30.8 (-34.9)
FL2222A	Negative	14.4 (-9.8)	Positive (S)	-22.2 (-30.1)
FL2222A	Positive (S)	11.3 (-11.5)	Positive (M)	-30.8 (-34.9)
FL2222A	Positive (W)	13.5 (-10.3)	Positive (M)	-36.4 (-38.0)
FL2222A	Positive (M)	12.2 (-11.0)	Negative	-41.8 (-41.0)
FL2222A	---	---	Negative	-39.8 (-39.9)
FL2222A	---	---	Positive (M)	-37.7 (-38.7)
FL2222A	---	---	Negative	-38.9 (-39.4)
FL2222B	Negative	16.3 (-8.7)	Negative	-38.2 (-39.0)
FL2222B	Positive (W)	14.5 (-9.7)	Negative	-34.6 (-37.0)
FL2222B	Negative	15.4 (-9.2)	Positive (M)	-31.0 (-35.0)
FL2222B	Negative	15.3 (-9.3)	Positive (M)	-32.1 (-35.6)
FL2222B	---	---	Negative	-33.5 (-36.4)
FL2222C	Negative	17.6 (-8.0)	Negative	-38.9 (-39.4)
FL2222C	Positive (W)	16.7 (-8.5)	Negative	-34.6 (-37.0)
FL2222C	Positive (M)	15.8 (-9.0)	Negative	-32.8 (-36.0)
FL2222C	Negative	18.1 (-7.7)	Negative	-29.2 (-34.0)
FL2222C	Positive (M)	14.0 (-10.0)	Positive (M)	-27.4 (-33.0)

Table C-1 (cont'd). Temperature Limits of Flammability: All Data

Fuel Name	Upper Limit Trials		Lower Limit Trials	
	Ignition Description	Temperature °F (°C)	Ignition Description	Temperature °F (°C)
FL2222C	Positive (M)	11.7 (-11.3)	Positve (M)	-28.7 (-33.7)
FL2222C	---	---	Negative	-30.3 (-34.6)
FL2223	Positive (M)	15.4 (-9.2)	Negative	-31.2 (-35.1)
FL2223	Positive (M)	17.8 (-7.9)	Negative	-28.1 (-33.4)
FL2223	Positive (W)	18.7 (-7.4)	Negative	-24.0 (-31.1)
FL2223	Negative	19.6 (-6.9)	Positive (M)	-22.9 (-30.5)
FL2223	Negative	22.6 (-5.2)	Positive (M)	-21.5 (-29.7)
FL2223	Negative	23.5 (-4.7)	Positive (M)	-23.4 (-30.8)
FL2223A	Positive (M)	11.1 (-11.6)	Negative	-37.3 (-38.5)
FL2223A	Positive (M)	14.0 (-10.0)	Negative	-34.2 (-36.8)
FL2223A	Positive (M)	18.1 (-7.7)	Negative	-26.5 (-32.5)
FL2223A	Positive (M)	20.5 (-6.4)	Negative	-24.2 (-31.2)
FL2223A	Negative	21.6 (-5.8)	Positive (M)	-20.0 (-28.9)
FL2223A	---	---	Positive (M)	-21.3 (-29.6)
FL2223B	Negative	21.0 (-6.1)	Negative	-27.8 (-33.2)
FL2223B	Positive (M)	17.4 (-8.1)	Negative	-23.6 (-30.9)
FL2223B	Negative	19.9 (-6.7)	Positive (S)	-20.6 (-29.2)
FL2223B	Positive (M)	18.7 (-7.4)	Positive (S)	-19.7 (-28.7)
FL2223C	Positive (M)	17.8 (-7.9)	Positive (M)	-21.8 (-29.9)
FL2223C	Negative	22.1 (-5.5)	Positive (S)	-14.6 (-25.9)
FL2223C	Positive (W)	20.5 (-6.4)	Positive (M)	-17.9 (-27.7)
FL2223C	Negative	21.4 (-5.9)	Positive (W)	-23.8 (-31.0)
FL2223C	---	---	Negative	-27.2 (-32.9)
FL2407	Positive (W)	17.9 (-7.8)	Positive (S)	-0.8 (-18.2)
FL2407	Negative	20.5 (-6.4)	Negative	-34.8 (-37.1)

Table C-1 (cont'd). Temperature Limits of Flammability: All Data

Fuel Name	Upper Limit Trials		Lower Limit Trials	
	Ignition Description	Temperature °F (°C)	Ignition Description	Temperature °F (°C)
FL2407	Negative	19.8 (-6.8)	Negative	-25.6 (-32.0)
FL2407	Postive (M)	17.1 (-8.3)	Positive (M)	-23.8 (-31.0)
FL2407	---	---	Negative	-27.0 (-32.8)
FL2407	---	---	Positive (M)	-25.2 (-31.8)
FL2407A	Positive (M)	14.4 (-9.8)	Positive (M)	-20.4 (-29.1)
FL2407A	Positive (M)	19.0 (-7.2)	Negative	-33.2 (-36.2)
FL2407A	Positive (W)	20.3 (-6.5)	Negative	-28.8 (-33.8)
FL2407A	Positive (W)	21.7 (-5.7)	Positive (M)	-23.4 (-30.8)
FL2407A	Negative	23.4 (-4.8)	Positive (M)	-25.1 (-31.7)
FL2407B	Positive (S)	7.7 (-13.5)	Positive (S)	-21.1 (-29.5)
FL2407B	Positive (S)	19.4 (-7.0)	Negative	-33.2 (-36.2)
FL2407B	Positive (W)	23.0 (-5.0)	Positive (M)	-28.7 (-33.7)
FL2407B	Negative	24.8 (-4.0)	Positive (M)	-30.3 (-34.6)
FL2407B	Negative	25.5 (-3.6)	Negative	-31.9 (-35.5)
FL2407C	Positive (M)	17.4 (-8.1)	Positive (S)	-21.5 (-29.7)
FL2407C	Positive (W)	19.8 (-6.8)	Negative	-33.2 (-36.2)
FL2407C	Negative	23.0 (-5.0)	Negative	-28.7 (-33.7)
FL2407C	Positive (W)	21.2 (-6.0)	Positive (M)	-24.3 (-31.3)
FL2407C	Negative	23.4 (-4.8)	Negative	-26.7 (-32.6)
FL2408	Negative	18.0 (-7.8)	Negative	-42.2 (-41.2)
FL2408	Negative	14.4 (-9.8)	Negative	-35.3 (-37.4)
FL2408	Positive (W)	10.4 (-12.0)	Positive (M)	-26.7 (-32.6)
FL2408	Negative	12.6 (-10.8)	Positive (M)	-29.9 (-34.4)
FL2408	Positive (W)	11.5 (-11.4)	Positive (M)	-33.9 (-36.6)
FL2408A	Positive (W)	8.8 (-12.9)	Negative	-31.4 (-35.2)

Table C-1 (cont'd). Temperature Limits of Flammability: All Data				
Fuel Name	Upper Limit Trials		Lower Limit Trials	
	Ignition Description	Temperature °F (°C)	Ignition Description	Temperature °F (°C)
FL2408A	Negative	13.3 (-10.4)	Positive (S)	-22.7 (-30.4)
FL2408A	Positive (W)	11.7 (-11.3)	Positive (M)	-27.2 (-32.9)
FL2408A	Negative	12.6 (-10.8)	Positive (W)	-28.4 (-33.8)
FL2408B	Positive (W)	7.9 (-13.4)	Negative	-31.4 (-35.2)
FL2408B	Negative	11.8 (-11.2)	Positive (S)	-22.4 (-30.2)
FL2408B	Negative	10.2 (-12.1)	Positive (S)	-27.4 (-33.0)
FL2408B	Positive (W)	9.0 (-12.8)	Positive (M)	-29.2 (-34.0)
FL2408B	---	---	Positive (W)	-31.0 (-35.0)
FL2408C	Negative	12.2 (-11.0)	Negative	-31.0 (-35.0)
FL2408C	Positive (W)	7.3 (-13.7)	Positive (S)	-22.4 (-30.2)
FL2408C	Negative	10.8 (-11.8)	Positive (S)	-27.2 (-32.9)
FL2408C	Positive (W)	9.9 (-12.3)	Positive (M)	-29.2 (-34.0)
FL2408C	---	---	Negative	-31.5 (-35.3)
FL2408C	---	---	Positive (M)	-30.3 (-34.6)
FL2409	Positive (M)	2.0 (-16.7)	---	---
FL2409	Positive (W)	4.3 (-15.4)	---	---
FL2409	Positive (W)	7.2 (-13.8)	---	---
FL2409	Negative	8.8 (-12.9)	---	---
FL2409	Negative	10.0 (-12.2)	---	---
FL2410	Positive (M)	-3.3 (-19.6)	---	---
FL2410	Positive (W)	-1.8 (-18.8)	---	---
FL2410	Positive (W)	1.0 (-17.2)	---	---
FL2410	Negative	2.3 (-16.5)	---	---

APPENDIX D

Flammability Limits of Hydrocarbons

Table D-1. Flammability Limits of Hydrocarbons(2)			
Hydrocarbon	Formula	Lower Limit	Upper Limit
Methane	CH_4	5.00	15.00 (12.9)*
Ethane	C_2H_6	3.00	12.50 (11.3)
Ethylene	C_2H_4	2.75	28.60 (15.8)
Propane	C_3H_8	2.12	9.35 (8.7)
Propylene	C_3H_6	2.00	11.10
Butane	C_4H_{10}	1.86	8.41 (7.2)
Isobutane	C_4H_{10}	1.80	8.44
1-Butene	C_4H_8	1.65	9.95
2-Butene	C_4H_8	1.75	9.70
Pentane	C_5H_{12}	1.40	7.80
Isopentane	C_5H_{12}	1.32	---
2,2-Dimethyl Propane	C_5H_{12}	1.38	7.50
Pentene	C_5H_{10}	1.42	8.70
Hexane	C_6H_{14}	1.18	7.40
Cyclohexane	C_6H_{12}	1.26	7.75
Benzene	C_6H_6	1.40	7.10
Heptane	C_7H_{16}	1.10	6.70
2,3-Dimethyl Pentane	C_7H_{16}	1.12	6.75
Toluene	C_7H_8	1.27	6.75
Octane	C_8H_{18}	0.95	---
Iso-octane	C_8H_{18}	0.97	(6.0)
o-Xylene	C_8H_{10}	1.00	6.00
Decane	$C_{10}H_{22}$	0.77	5.35

* The values in parentheses were measured in a constant volume bomb.(7)

APPENDIX E

Regression Coefficients for Upper Temperature Flammability Limit Data in Figure 5

Table E-1. Regression Coefficients for the Expression: UTLF = a + b*RVP + c*RVP^2 Where UTLF is the upper temperature limit of flammability and RVP is Reid Vapor Pressure				
Fuel Group	r^2	a	b	c
Base Fuels	0.99	-3.36	9.80	-1.03
10% Ethanol Blends	0.96	60.87	-5.99	n/a
15% MTBE Blends	0.94	64.64	-6.94	n/a
Ethanol/MTBE Commingled Blends	0.95	82.06	-8.89	n/a

APPENDIX F

Vapor Phase Speciation of Test Fuels

VAPOR PHASE SPECIATION OF BASELINE GASOLINES
At UTLF

Fuel Name	FL2221	FL2222	FL2223	FL2407	FL2408	FL2409	FL2410
UTLF, degs F	15.80	17.60	19.40	19.40	12.20	8.80	2.30
Total Concentration, mole %	8.13	8.00	6.74	7.64	6.57	7.05	6.77

Species Concentrations in ppm

SPECIES NAME							
iso-BUTANE	851.58	521.38	318.23	1216.70	813.37	766.99	667.17
BUTENE-1	58.64	35.57	0.00	125.86	348.11	1882.15	3307.94
N-BUTANE	35105.57	31924.42	18964.73	5849.45	3625.99	3203.71	2644.50
t-BUTENE-2	161.69	88.18	122.75	168.42	141.93	89.02	89.43
NEOPENTANE	214.87	198.61	205.69	67.17	63.46	72.68	52.16
c-BUTENE-2	225.10	150.30	153.33	301.42	193.89	113.19	114.79
3-M BUTENE-1	647.47	243.85	226.99	2025.13	327.56	204.14	100.00
I-PENTANE	10450.14	9156.14	9183.51	27552.89	31138.14	33919.76	34858.86
PENTENE-1	456.40	400.67	393.21	1131.60	869.71	697.02	385.09
2-M BUTENE-1	909.45	825.43	849.04	1776.51	1274.75	1061.68	756.22
N-PENTANE	2536.77	2395.42	2441.97	7066.50	8857.06	10449.53	10957.39
trans-PENTENE-2	1125.43	1105.44	1125.30	2311.20	1573.00	1535.04	1105.30
cis-PENTENE-2	607.30	593.03	605.62	1235.20	841.01	742.58	559.87
2-M BUTENE-2	1760.29	1691.63	1702.51	2551.15	1648.06	1686.45	1273.33
22DMBUTANE	1551.16	1595.13	1686.26	2140.96	3284.63	3808.29	4247.55
OLEFIN	186.42	201.71	179.73	333.16	214.57	197.00	133.65
CYCLOPENTENE	50.51	61.13	51.03	57.34	40.00	0.00	804.03
4-M-PENTENE-1	83.31	106.02	105.62	93.02	85.24	95.81	0.00
CYCLOPENTANE	4616.75	4938.75	4939.51	525.54	669.18	802.88	0.00
2,3-DM BUTANE	1397.70	1528.97	1530.75	946.66	544.80	498.52	344.04
UNKNOWN	72.40	77.99	137.42	51.05	38.96	0.00	0.00
2-M PENTANE	2932.93	108.20	3206.40	1788.94	1095.78	981.32	0.00
4-M-trans-PENTENE-2	200.34	3195.71	401.99	148.06	112.00	190.15	50.79
3-M PENTANE	1410.15	1659.54	1614.09	1123.32	662.82	602.36	438.30
2-M PENTENE-1	144.48	187.10	167.26	154.88	97.98	0.00	0.00
HEXENE-1	103.52	267.78	120.51	127.18	91.13	98.93	82.58
N-HEXANE	418.85	502.99	482.41	645.37	353.82	302.35	224.75
UNKNOWN	84.65	104.16	96.84	104.11	61.33	58.95	40.74
trans-HEXENE-2	166.76	214.37	205.63	212.35	127.83	89.83	68.61
2-M PENTENE-2	158.74	218.69	217.94	136.30	83.65	106.14	78.62
UNKNOWN	114.76	137.50	139.99	106.45	0.00	0.00	0.00
UNKNOWN	37.27	47.39	50.40	0.00	67.22	50.24	36.62
cis-HEXENE-2	104.95	111.40	137.41	136.07	74.55	68.45	41.89
UNKNOWN	179.13	207.49	208.40	174.42	111.88	98.86	0.00
22DMPENTANE	39.90	44.71	44.16	47.72	25.40	28.43	61.87
M-cyc-PENTANE	307.12	358.88	364.06	632.51	376.85	338.49	224.98
2,4-DM PENTANE	489.08	575.86	614.23	396.22	199.52	168.50	126.05
BENZENE	1305.51	1654.90	1669.31	1675.49	790.69	803.72	603.11
3,3-DM PENTANE	41.43	38.85	0.00	79.96	0.00	0.00	0.00
CYCLOHEXANE	3139.54	3536.38	3725.77	68.69	34.92	51.86	0.00
2-M HEXANE	185.76	212.15	217.06	379.77	197.10	163.91	116.48
2,3-DM PENTANE	670.83	770.78	757.23	263.94	133.20	107.35	91.11
UNKNOWN	14.74	24.19	25.72	29.32	0.00	0.00	0.00
CYCLOHEXENE	247.71	269.20	262.98	484.39	241.72	207.88	166.94

VAPOR PHASE SPECIATION OF BASELINE GASOLINES (Continued)
At UTLF

Fuel Name	FL2221	FL2222	FL2223	FL2407	FL2408	FL2409	FL2410
UTLF, degs F	15.80	17.60	19.40	19.40	12.20	8.80	2.30
Total Concentration, mole %	8.13	8.00	6.74	7.64	6.57	7.05	6.77
	Species Concentrations in ppm						
SPECIES NAME							
UNKNOWN	57.68	68.00	66.20	114.29	58.87	58.30	38.99
cis-1,3-DM-cyc-PENTANE	40.21	53.82	49.75	81.39	43.60	38.24	31.56
trans-1,3-DM-cyc-PENTANE	29.12	35.32	35.43	52.22	28.27	18.39	0.00
3-E PENTANE	12.33	0.00	0.00	61.31	31.19	23.83	21.93
2,2,4-TM PENTANE	1019.05	1184.28	1595.10	2293.12	989.71	811.03	589.35
trans-HEPTENE-3	580.13	706.33	740.46	207.06	100.68	88.94	64.58
cis-HEPTENE-3	26.64	47.27	27.35	26.44	0.00	0.00	0.00
trans-HEPTENE-2	30.18	30.85	0.00	53.37	31.46	19.31	20.84
M-cyc-HEXANE	29.81	63.52	44.28	116.94	58.64	41.91	41.16
E-cyc-PENTANE	38.84	32.54	42.18	282.68	82.22	99.73	45.67
M-cyc-HEXENE2	83.48	94.84	85.84	379.77	158.51	121.41	72.54
2,3,4-TM PENTANE	132.05	149.44	156.03	345.05	165.06	138.66	89.28
TOLUENE	2236.49	3087.01	2921.28	3585.74	1496.41	1673.09	1220.44
2,3-DM HEXANE	17.06	61.08	61.88	127.34	54.57	55.43	35.66
2-M HEPTANE	15.93	42.55	36.82	81.04	36.61	0.00	0.00
3-M HEPTANE	0.00	0.00	37.17	86.67	42.96	29.16	0.00
4-M HEPTANE	19.93	54.90	41.39	52.73	0.00	0.00	0.00
ETHYL BENZENE	355.41	455.82	469.36	454.49	173.16	199.73	136.79
M-XYLENE	521.15	707.72	643.90	787.31	320.06	347.61	255.50
P-XYLENE	286.05	465.49	432.49	450.61	159.56	180.32	181.77
O-XYLENE	247.89	340.12	305.73	344.35	172.80	182.68	0.00
Total Concentration, ppm	81346.48	79968.90	67445.64	76426.35	65737.15	70471.92	67700.80

VAPOR PHASE SPECIATION OF ETHANOL-GASOLINE BLENDS
At UTLF

Fuel Name	FL2221A	FL2222A	FL2223A	FL2407A	FL2408A
UTLF, degs F	12.20	14.00	21.20	23.00	12.20
Total Concentration, mole %	9.45	8.98	9.62	10.93	8.04
			Species Concentrations in ppm		
<u>SPECIES NAME</u>					
iso-BUTANE	717.76	444.07	279.04	1031.30	642.46
BUTENE-1	55.82	0.00	0.00	72.45	47.98
N-BUTANE	29992.63	25795.03	17362.40	5010.80	3023.49
t-BUTENE-2	125.72	74.70	94.84	136.23	112.65
NEOPENTANE	176.10	166.36	135.77	42.23	50.21
c-BUTENE-2	174.41	107.37	168.71	197.81	159.56
ETOH	20998.88	22007.69	28894.16	32764.63	16583.60
3-M BUTENE-1	2435.30	2572.69	2627.46	3937.80	2678.49
I-PENTANE	9886.51	8275.99	9024.56	27038.71	29067.88
PENTENE-1	559.35	546.47	370.17	1484.92	913.61
2-M BUTENE-1	860.97	738.73	773.79	1880.23	1185.68
N-PENTANE	2334.52	2103.32	2396.80	6921.48	8222.51
BUTADIENE-1,3	0.00	0.00	0.00	359.51	126.31
trans-PENTENE-2	977.69	948.90	1035.51	2376.11	1458.94
cis-PENTENE-2	533.41	478.16	564.05	1322.12	747.43
2-M BUTENE-2	1476.18	1341.79	1611.48	2380.76	1478.84
22DMBUTANE	1403.31	1398.88	1636.93	2296.07	3056.44
OLEFIN	160.45	205.78	199.29	344.35	195.10
CYCLOPENTENE	45.70	54.85	49.24	62.40	0.00
4-M-PENTENE-1	58.87	83.85	86.90	119.60	106.34
CYCLOPENTANE	4095.76	3994.47	4865.70	506.12	631.16
2,3-DM BUTANE	1243.01	1248.32	1523.59	920.95	517.76
UNKNOWN	75.10	93.27	93.87	47.86	63.54
2-M PENTANE	2675.86	2614.65	3383.09	1743.87	1040.43
4-M-trans-PENTENE-2	67.70	324.39	82.15	138.68	92.20
3-M PENTANE	1248.83	1313.05	1564.72	1104.49	633.48
2-M PENTENE-1	121.42	136.50	154.12	143.39	89.31
HEXENE-1	77.32	93.11	98.97	104.55	100.52
N-HEXANE	389.09	384.54	495.00	633.28	335.05
UNKNOWN	112.67	51.55	93.63	107.29	56.65
trans-HEXENE-2	158.67	150.87	197.51	215.36	123.80
2-M PENTENE-2	169.40	121.78	207.57	189.79	107.68
UNKNOWN	108.04	103.73	139.91	123.20	75.58
UNKNOWN	38.16	35.35	55.23	58.79	32.42
cis-HEXENE-2	90.18	103.41	123.16	148.22	93.87
UNKNOWN	164.18	168.61	197.24	177.92	116.87
22DMPENTANE	37.86	37.52	48.93	40.72	26.05
M-cyc-PENTANE	292.13	296.48	356.34	620.44	361.57
2,4-DM PENTANE	431.73	459.34	569.59	397.14	188.66
BENZENE	1025.34	1105.39	1399.59	1299.39	721.92
3,3-DM PENTANE	0.00	35.48	38.58	66.87	51.48
CYCLOHEXANE	2786.60	3036.25	3955.43	65.60	42.36
2-M HEXANE	20.87	180.42	39.12	380.90	198.13
2,3-DM PENTANE	171.60	638.47	244.84	260.23	132.07

VAPOR PHASE SPECIATION OF ETHANOL-GASOLINE BLENDS (Continued)
At UTLF

Fuel Name	FL2221A	FL2222A	FL2223A	FL2407A	FL2408A
UTLF, degs F	12.20	14.00	21.20	23.00	12.20
Total Concentration, mole %	9.45	8.98	9.62	10.93	8.04
			Species Concentrations in ppm		
<u>SPECIES NAME</u>					
UNKNOWN	616.13	24.64	883.32	23.52	0.00
CYCLOHEXENE	193.51	201.34	304.95	467.73	243.66
UNKNOWN	56.36	50.90	69.16	101.09	62.50
cis-1,3-DM-cyc-PENTANE	40.69	37.87	52.43	80.66	49.00
trans-1,3-DM-cyc-PENTANE	30.40	28.84	37.36	48.02	26.98
3-E PENTANE	0.00	0.00	0.00	50.39	35.92
2,2,4-TM PENTANE	947.40	997.58	1661.90	2237.68	997.79
trans-HEPTENE-3	531.09	561.12	766.29	211.27	102.61
n-HEPTANE	0.00	0.00	36.91	26.76	32.72
cis-HEPTENE-3	57.75	38.79	52.66	0.00	0.00
trans-HEPTENE-2	0.00	24.50	30.98	51.65	0.00
M-cyc-HEXANE	30.95	45.74	61.49	110.11	63.59
E-cyc-PENTANE	0.00	33.90	89.38	291.59	132.58
M-cyc-HEXENE2	62.32	71.98	104.79	459.01	176.49
2,3,4-TM PENTANE	187.65	121.94	165.41	367.91	135.30
TOLUENE	1870.24	2082.18	2722.30	3225.38	1563.05
2,3-DM HEXANE	40.47	60.18	63.09	131.95	64.34
2-M HEPTANE	0.00	0.00	0.00	84.89	32.93
3-M HEPTANE	0.00	0.00	0.00	88.33	45.99
ETHYL BENZENE	289.57	289.98	417.77	390.85	201.79
M-XYLENE	407.83	456.79	617.98	706.75	342.15
P-XYLENE	236.45	251.84	367.40	421.11	217.19
O-XYLENE	195.33	234.03	310.95	331.00	190.82
Total Concentration, ppm	94369.26	89685.76	96055.48	109182.19	80407.49

VAPOR PHASE SPECIATION OF MTBE-GASOLINE BLENDS
At UTLF

Fuel Name	FL2221B	FL2222B	FL2223B	FL2407B	FL2408B
UTLF, degs F	14.00	15.80	19.40	24.80	10.40
Total Concentration, mole %	8.34	8.00	8.01	8.58	7.04
	Species Concentrations in ppm				
SPECIES NAME					
iso-BUTANE	631.60	376.61	259.27	705.65	581.83
METHANOL	5493.31	5627.77	7641.33	8074.94	5788.72
BUTENE-1	600.84	625.19	732.44	626.91	497.40
N-BUTANE	26164.51	22697.79	15572.84	3833.77	2706.68
t-BUTENE-2	149.82	58.61	77.91	111.11	117.05
NEOPENTANE	170.44	143.65	109.59	0.00	31.21
c-BUTENE-2	164.61	118.77	129.34	177.02	155.05
3-M BUTENE-1	380.25	155.82	197.39	419.20	266.04
I-PENTANE	8228.21	6619.21	7556.65	21049.02	24601.34
PENTADIENE-1,4	235.83	462.13	455.43	640.79	440.48
PENTENE-1	343.00	318.44	390.36	876.69	722.01
2-M BUTENE-1	686.14	651.79	709.33	1349.96	1018.98
N-PENTANE	2009.64	1907.70	2078.95	5604.96	7208.63
BUTADIENE-1,3	0.00	0.00	0.00	66.99	91.69
trans-PENTENE-2	867.62	877.79	945.34	1783.41	1305.49
cis-PENTENE-2	464.38	451.84	488.66	933.56	670.28
2-M BUTENE-2	1755.67	1850.96	1644.31	2063.51	1408.91
22DMBUTANE	1225.87	1226.22	1376.75	1712.63	2671.66
OLEFIN	153.37	130.25	184.01	265.56	176.69
CYCLOPENTENE	52.35	0.00	53.63	48.53	12.92
4-M-PENTENE-1	82.07	87.89	87.53	79.10	0.00
CYCLOPENTANE	3814.20	3647.95	4176.84	413.82	553.22
2,3-DM BUTANE	1020.75	981.32	1136.28	648.53	410.71
MTBE	12563.61	13301.30	15140.18	18398.72	11364.25
2-M PENTANE	2640.66	2681.80	2964.59	1408.50	850.12
4-M-trans-PENTENE-2	897.52	866.21	658.25	68.05	46.44
3-M PENTANE	1225.00	1284.66	1464.44	984.21	578.45
2-M PENTENE-1	144.82	131.32	167.58	125.26	80.33
HEXENE-1	184.52	113.46	207.13	100.79	65.88
N-HEXANE	350.41	360.03	445.94	544.48	299.46
UNKNOWN	47.15	98.50	90.03	91.06	36.15
trans-HEXENE-2	136.90	133.26	189.63	174.39	105.50
2-M PENTENE-2	108.87	141.57	189.20	111.48	70.27
UNKNOWN	92.32	84.05	123.92	98.46	57.09
UNKNOWN	31.08	0.00	55.15	36.15	0.00
cis-HEXENE-2	81.12	87.10	115.05	111.60	65.48
UNKNOWN	144.39	158.95	174.99	156.86	82.23
22DMPENTANE	33.09	42.08	40.96	40.99	23.49
M-cyc-PENTANE	257.61	281.68	290.07	531.84	313.03
2,4-DM PENTANE	437.04	416.44	469.63	371.77	169.93
BENZENE	1108.17	1139.32	1240.63	1270.09	666.58
3,3-DM PENTANE	34.59	0.00	2836.96	67.52	0.00
CYCLOHEXANE	2560.54	2698.08	43.19	61.68	34.44
2-M HEXANE	152.03	161.22	200.00	337.76	170.00

VAPOR PHASE SPECIATION OF MTBE-GASOLINE BLENDS (Continued)
At UTLF

Fuel Name	FL2221B	FL2222B	FL2223B	FL2407B	FL2408B
UTLF, degs F	14.00	15.80	19.40	24.80	10.40
Total Concentration, mole %	8.34	8.00	8.01	8.58	7.04
	Species Concentrations in ppm				
SPECIES NAME					
2,3-DM PENTANE	541.74	581.82	721.28	240.11	118.59
UNKNOWN	0.00	0.00	37.02	23.18	0.00
CYCLOHEXENE	195.80	202.93	259.06	418.37	213.66
UNKNOWN	52.05	51.00	68.99	99.36	55.51
cis-1,3-DM-cyc-PENTANE	39.30	38.11	43.91	67.93	44.86
trans-1,3-DM-cyc-PENTANE	27.69	0.00	33.56	41.70	0.00
3-E PENTANE	0.00	0.00	0.00	48.72	30.81
2,2,4-TM PENTANE	854.53	892.53	1326.92	1942.52	849.18
trans-HEPTENE-3	493.77	537.95	598.04	178.35	88.23
n-HEPTANE	0.00	0.00	0.00	17.88	0.00
cis-HEPTENE-3	53.99	25.45	0.00	0.00	0.00
trans-HEPTENE-2	17.10	52.70	0.00	47.78	0.00
M-cyc-HEXANE	48.52	0.00	43.10	92.84	33.19
E-cyc-PENTANE	0.00	34.10	32.61	230.61	72.28
M-cyc-HEXENE2	66.79	75.34	68.93	342.10	102.15
2,3,4-TM PENTANE	151.61	112.09	132.42	266.36	117.94
TOLUENE	1897.35	2375.72	2276.03	3084.73	1320.09
2,3-DM HEXANE	0.00	63.21	70.76	110.48	37.83
2-M HEPTANE	0.00	26.51	0.00	77.64	32.69
3-M HEPTANE	0.00	0.00	0.00	78.95	40.26
ccc123TMcycC5	0.00	0.00	0.00	34.06	0.00
ETHYL BENZENE	265.68	448.59	358.02	388.60	155.61
M-XYLENE	363.86	601.61	461.75	699.49	288.89
P-XYLENE	261.25	405.53	276.74	385.10	155.08
O-XYLENE	183.36	298.33	201.50	328.32	153.37

VAPOR PHASE SPECIATION OF ETHANOL/MTBE-GASOLINE BLENDS
At UTLF

Fuel Name	FL2221C	FL2222C	FL2223C	FL2407C	FL2408C
UTLF, degs F	6.80	17.60	21.20	23.00	10.40
Total Concentration, mole %	7.33	9.75	9.50	10.03	6.72
	Species Concentrations in ppm				
SPECIES NAME					
iso-BUTANE	607.40	427.50	277.97	839.08	526.13
METHANOL	823.76	977.92	1036.32	1021.38	846.17
BUTENE-1	214.37	219.96	243.35	294.90	217.88
N-BUTANE	24269.54	26555.66	16467.80	4152.95	2506.50
t-BUTENE-2	115.50	97.27	77.56	128.21	104.63
NEOPENTANE	153.77	184.88	117.90	27.31	33.21
c-BUTENE-2	151.37	138.36	118.29	189.85	134.33
ETOH	13065.45	19181.10	21520.87	28435.74	11583.71
3-M BUTENE-1	1593.14	2119.90	2923.26	288.70	1054.18
I-PENTANE	7023.75	8139.04	8578.55	23114.34	23288.15
PENTADIENE-1,4	32.66	555.19	615.04	0.00	0.00
PENTENE-1	277.30	543.24	579.20	924.96	593.08
2-M BUTENE-1	581.79	798.26	835.88	1437.65	908.90
N-PENTANE	1687.64	2211.11	2318.37	6034.96	6776.26
BUTADIENE-1,3	0.00	0.00	0.00	86.23	56.89
trans-PENTENE-2	720.80	1046.72	1016.79	1888.07	1162.21
cis-PENTENE-2	385.76	542.24	536.35	1022.63	634.50
2-M BUTENE-2	1090.50	1614.43	1487.87	2084.60	1244.59
UNKNOWN	0.00	0.00	0.00	35.99	18.45
22DMBUTANE	1059.35	1410.20	1516.97	1994.63	2540.66
OLEFIN	119.08	157.41	187.65	342.80	156.18
CYCLOPENTENE	15.59	38.96	53.63	64.48	0.00
4-M-PENTENE-1	81.73	50.67	115.80	134.40	11.24
CYCLOPENTANE	3053.01	4185.30	4543.94	508.40	517.71
2,3-DM BUTANE	894.90	1247.72	1353.78	816.03	413.88
MTBE	4155.20	6368.54	6887.81	7554.62	4072.46
2-M PENTANE	2051.34	2899.07	3149.24	1734.92	962.12
4-M-trans-PENTENE-2	228.57	574.79	767.16	645.66	260.77
3-M PENTANE	915.03	1471.84	1637.45	1065.92	591.87
2-M PENTENE-1	87.39	152.26	174.11	145.01	79.73
HEXENE-1	53.03	163.11	209.98	117.22	80.13
N-HEXANE	275.76	415.18	479.52	543.26	283.35
UNKNOWN	55.53	52.34	146.13	96.20	34.13
trans-HEXENE-2	105.27	150.72	194.98	192.48	100.64
2-M PENTENE-2	86.24	132.15	201.19	171.26	88.76
UNKNOWN	68.29	108.12	134.69	112.20	0.00
UNKNOWN	0.00	37.53	54.36	50.00	55.98
cis-HEXENE-2	66.25	116.55	134.52	130.33	71.85
UNKNOWN	119.66	178.16	199.93	156.94	99.61
22DMPENTANE	27.68	48.08	48.42	35.58	24.79
M-cyc-PENTANE	211.72	312.87	336.55	543.80	313.03
2,4-DM PENTANE	316.32	494.31	541.71	388.22	169.53
BENZENE	754.37	1109.43	1222.50	1136.47	623.23
3,3-DM PENTANE	0.00	36.70	38.85	59.31	31.73

VAPOR PHASE SPECIATION OF ETHANOL/MTBE-GASOLINE BLENDS (Continued)
At UTLF

Fuel Name	FL2221C	FL2222C	FL2223C	FL2407C	FL2408C
UTLF, degs F	6.80	17.60	21.20	23.00	10.40
Total Concentration, mole %	7.33	9.75	9.50	10.03	6.72
	Species Concentrations in ppm				
SPECIES NAME					
CYCLOHEXANE	2013.05	3284.91	3677.83	52.77	30.40
2-M HEXANE	116.67	201.16	222.74	332.34	161.52
2,3-DM PENTANE	414.96	711.23	776.16	244.09	105.04
UNKNOWN	0.00	0.00	36.24	23.75	0.00
CYCLOHEXENE	145.72	245.45	263.42	449.96	201.50
UNKNOWN	35.09	56.84	54.36	95.49	50.15
cis-1,3-DM-cyc-PENTANE	13.93	42.79	44.01	69.12	37.56
trans-1,3-DM-cyc-PENTANE	10.55	33.15	33.76	43.13	19.85
3-E PENTANE	0.00	0.00	0.00	50.73	25.20
2,2,4-TM PENTANE	643.15	1090.25	1508.72	2091.01	782.88
trans-HEPTENE-3	360.31	610.29	676.57	173.03	84.73
trans-HEPTENE-2	5.65	0.00	28.27	42.25	30.44
M-cyc-HEXANE	0.00	38.55	66.58	92.91	48.22
E-cyc-PENTANE	10.32	32.44	42.52	269.09	67.53
M-cyc-HEXENE2	44.41	86.50	79.64	386.51	95.57
2,3,4-TM PENTANE	79.71	132.72	151.58	333.70	132.42
TOLUENE	1218.93	2038.57	2465.71	2689.36	1321.99
2,3-DM HEXANE	0.00	38.36	69.57	106.92	76.63
2-M HEPTANE	0.00	32.90	31.15	76.46	30.43
3-M HEPTANE	0.00	0.00	0.00	72.21	30.94
ETHYL BENZENE	160.59	335.84	393.88	345.25	127.35
M-XYLENE	200.13	535.95	603.43	675.72	258.16
P-XYLENE	111.28	377.52	379.87	411.61	140.95
O-XYLENE	70.83	263.58	303.93	401.67	115.76
Total Concentration, ppm	73251.08	97453.79	94992.16	100276.78	67248.38

APPENDIX G

Stratification Experiments

STRATIFICATION EXPERIMENT I

Variables are Time and Fuel Temperature

Test Fuel	FL2407	FL2407	FL2407	FL2407
Hours out of 45 deg. Cold Box	0.25	0.58	2.00	2.00
Liquid Fuel Temperature, degs F	57.50	62.50	72.50	73.00
Room Temperature, degs F	74.30	75.20	75.20	77.00
Total Concentration, mole%	11.73	13.71	16.80	17.87

Species Concentrations in ppm

iso-BUTANE	1052.03	1108.86	1299.00	1332.38
BUTENE-1	71.79	91.45	90.74	86.28
N-BUTANE	5952.91	6509.68	7598.65	8111.42
t-BUTENE-2	184.27	193.23	221.26	224.59
NEOPENTANE	40.90	35.58	51.68	50.50
c-BUTENE-2	292.64	324.71	347.16	365.09
3MBUTENE-1	597.97	724.43	770.80	814.84
I-PENTANE	40974.01	46079.75	54389.76	59073.00
PENTENE-1	1690.44	1957.95	2394.44	2439.58
2MBUTENE-1	2679.87	3030.09	3662.02	3914.57
N-PENTANE	10959.29	12480.26	14962.85	16366.30
BUTADIENE-13	143.41	176.07	341.52	287.24
trans-PENTENE-2	3463.63	4010.20	4910.22	5255.88
33DMBUTENE-1	38.20	63.34	141.69	90.18
cis-PENTENE-2	1864.03	2165.56	2731.17	2855.55
2MBUTENE-2	3784.83	4508.93	5348.57	5773.66
UNKNOWN	89.08	59.38	659.40	396.97
1trans, 3-PENTADIENE	42.31	47.78	136.69	71.46
22DMBUTANE	3741.46	4194.38	5489.65	5523.97
C6-OLEFIN	492.37	567.43	849.46	717.87
CYCLOPENTENE	74.03	78.99	123.75	82.20
4M-PENTENE-1	144.30	180.84	339.08	216.24
3M-PENTENE-1	740.83	859.48	1112.33	1109.29
23DMBUTANE	1657.72	1887.74	2341.80	2461.99
UNKNOWN	132.67	156.94	217.07	147.24
UNKNOWN	90.15	106.34	165.61	103.25
2MPENTANE	3099.71	3694.08	4378.39	4693.73
4MtPENTENE-2	217.86	178.67	585.80	277.32
3MPENTANE	1940.59	2234.39	2735.64	2943.57
2MPENTENE-1	266.24	295.06	355.67	377.48
HEXENE-1	185.67	199.92	229.34	274.71
N-HEXANE	1090.15	1280.30	1556.45	1709.22
UNKNOWN	0.00	0.00	255.87	261.93
UNKNOWN	180.29	219.37	0.00	0.00
t-HEXENE-2	378.31	453.97	539.88	583.38
2MPENTENE-2	335.00	389.83	482.83	514.66
UNKNOWN	133.54	166.16	0.00	196.76
UNKNOWN	220.71	262.76	317.35	339.13
UNKNOWN	74.35	100.04	111.17	103.45
cis-HEXENE-2	212.79	276.93	300.76	295.85
UNKNOWN	313.36	369.97	449.15	493.69
22DMPENTANE	72.93	88.22	94.69	111.78

STRATIFICATION EXPERIMENT I (Continued)
Variables are Time and Fuel Temperature

Test Fuel	FL2407	FL2407	FL2407	FL2407
Hours out of 45 deg. Cold Box	0.25	0.58	2.00	2.00
Liquid Fuel Temperature, degs F	57.50	62.50	72.50	73.00
Room Temperature, degs F	74.30	75.20	75.20	77.00
Total Concentration, mole%	11.73	13.71	16.80	17.87

Species Concentrations in ppm

MCYCPENTANE	1135.93	1351.97	1634.55	1813.70
24DMPENTANE	796.15	970.95	1129.99	1294.31
223TMBUTANE	33.81	82.67	63.91	103.23
UNKNOWN	0.00	16.04	0.00	29.89
UNKNOWN	15.59	20.33	15.22	16.62
BENZENE	2056.39	2754.95	3207.47	3621.10
33DMPENTANE	89.10	113.35	136.74	168.13
CYCLOHEXANE	103.05	126.25	156.10	181.91
UNKNOWN	23.60	24.17	31.12	63.13
2MHEXANE	45.62	54.00	64.56	65.85
23DMPENTANE	767.38	916.03	1136.15	1238.54
UNKNOWN	538.23	645.79	807.45	881.61
11DMCYPENTANE	28.81	40.58	44.49	49.54
UNKNOWN	40.35	45.45	53.76	58.05
CYCLOHEXENE	947.50	1129.80	1384.23	1533.40
3MHEXANE ?	208.82	243.33	303.77	327.69
c13DMCYPENTANE	165.43	190.57	240.18	255.99
t13DMCYPENTANE	102.17	111.71	144.01	147.37
3EPENTANE	120.02	139.70	174.58	192.43
224TMPENTANE	5210.03	6185.54	7683.31	8262.09
UNKNOWN	44.83	47.74	59.99	67.25
UNKNOWN	99.69	112.96	138.65	139.09
t-HEPTENE-3	428.11	523.93	661.94	709.35
UNKNOWN	76.52	114.79	146.05	151.03
UNKNOWN	39.43	46.59	57.28	60.43
c-HEPTENE-3	44.22	49.92	58.37	60.10
t-HEPTENE-2	0.00	0.00	0.00	0.00
UNKNOWN	93.15	99.39	132.17	136.68
UNKNOWN	38.75	0.00	87.55	50.02
UNKNOWN	102.99	126.84	156.36	166.54
UNKNOWN	213.88	252.09	329.76	359.01
McycHEXANE	0.00	12.76	0.00	16.46
22DMHEXANE	0.00	0.00	47.83	0.00
EcycPENTANE	686.51	829.30	1047.32	1135.18
223TMPENTANE	0.00	0.00	173.07	0.00
McycHEXENE1	956.27	1166.22	1259.78	1656.23
1t2c4TMcycPENTANE	40.34	55.03	66.42	86.53
UNKNOWN	0.00	0.00	0.00	53.74
1t2c3TMcycPENTANE	0.00	0.00	38.58	40.46
234TMPENTANE	778.54	950.73	1194.50	1274.25
TOLUENE	5705.95	7682.23	9412.29	10520.78
23DMHEXANE	326.70	393.59	501.31	585.79

STRATIFICATION EXPERIMENT I (Continued)
Variables are Time and Fuel Temperature

Test Fuel	FL2407	FL2407	FL2407	FL2407
Hours out of 45 deg. Cold Box	0.25	0.58	2.00	2.00
Liquid Fuel Temperature, degs F	57.50	62.50	72.50	73.00
Room Temperature, degs F	74.30	75.20	75.20	77.00
Total Concentration, mole%	11.73	13.71	16.80	17.87

Species Concentrations in ppm

2MHEPTANE	186.94	236.85	293.95	313.16
4MC7	77.55	95.49	119.30	126.72
112TMcycC5	16.36	21.75	26.56	27.31
UNKNOWN	0.00	0.00	0.00	0.00
3EC6	195.16	257.25	329.46	358.38
2M3EPENTANE	22.03	76.72	127.47	139.61
34DMHexane	0.00	0.00	0.00	0.00
t14DMcycC6	0.00	0.00	30.61	45.22
UNKNOWN	129.43	171.23	196.59	228.60
UNKNOWN	0.00	61.16	64.88	118.08
1-0CTENE	0.00	40.63	0.00	56.91
N-OCTANE	98.78	120.73	188.93	184.53
UNKNOWN	0.00	0.00	55.56	33.34
33DMC7&35DMC7-I	0.00	0.00	34.67	0.00
ETHYLBENZENE	794.29	1110.31	1341.01	1429.57
M-XYLENE	1461.69	2013.87	2466.03	2702.89
P-XYLENE	792.28	1106.21	1346.34	1346.02
UNKNOWN	0.00	31.47	30.33	48.95
2MC8	0.00	48.58	51.48	59.50
3MOCTANE	40.62	55.79	66.74	72.40
O-XYLENE&112TMcycC6	829.47	1065.71	1333.57	1441.19
UNKNOWN	33.27	29.54	33.48	31.73
iC3BENZENE	0.00	33.30	39.17	42.98
nC3BENZENE	140.28	161.58	188.59	190.18
1M3EBENZENE	368.73	429.07	486.43	522.43
1M4EBENZENE	175.03	196.36	281.63	236.09
23DMOCTANE	130.57	141.49	168.10	159.79
2MC9 or 3EOCTANE	0.00	152.87	162.70	170.31
3MC9	0.00	0.00	0.00	0.00
124TMBENZENE	0.00	0.00	646.40	0.00
UNKNOWN	0.00	0.00	0.00	0.00
UNKNOWN	0.00	0.00	99.65	0.00
1M3iC3BENZENE	0.00	0.00	0.00	0.00
UNKNOWN	0.00	0.00	81.72	0.00
1M2iC3BENZENE	0.00	0.00	21.48	0.00
UNKNOWN	0.00	0.00	25.53	0.00
1M3nC3BENZENE	0.00	0.00	60.28	0.00
1M4nC3BENZENE	0.00	0.00	35.47	0.00
nC4BENZENE	0.00	0.00	52.81	0.00
1M2nC3BENZENE	0.00	0.00	32.57	0.00
UNKNOWN	0.00	0.00	29.08	0.00
14DM2EBENZENE	0.00	0.00	58.90	0.00

STRATIFICATION EXPERIMENT I (Continued)
Variables are Time and Fuel Temperature

Test Fuel	FL2407	FL2407	FL2407	FL2407
Hours out of 45 deg. Cold Box	0.25	0.58	2.00	2.00
Liquid Fuel Temperature, degs F	57.50	62.50	72.50	73.00
Room Temperature, degs F	74.30	75.20	75.20	77.00
Total Concentration, mole%	11.73	13.71	16.80	17.87

Species Concentrations in ppm

IC11	0.00	0.00	84.25	0.00
1245TMBENZENE	0.00	0.00	31.43	0.00
UNKNOWN	0.00	0.00	34.77	0.00
UNKNOWN	0.00	0.00	29.63	0.00
UNKNOWN	0.00	0.00	44.80	0.00
nC5BENZENE	0.00	0.00	21.54	0.00
t1M2(4MP)cycC5	0.00	0.00	45.24	0.00
1tC44EBENZENE	0.00	0.00	52.16	0.00
Total Concentration, ppm	117312.96	137094.34	168021.47	178707.59

STRATIFICATION EXPERIMENT I (Continued)
Variables are Time and Fuel Temperature

Test Fuel	FL2407	FL2407	FL2407	FL2407
Hours out of 45 deg. Cold Box	4.00	5.75	7.75	24.00
Liquid Fuel Temperature, degs F	76.00	76.00	76.50	74.00
Room Temperature, degs F	77.50	75.70	76.10	73.80
Total Concentration, mole%	20.20	22.14	23.22	21.89

Species Concentrations in ppm

iso-BUTANE	1422.16	1521.27	1568.54	1480.00
BUTENE-1	113.01	107.66	80.94	108.14
N-BUTANE	8795.39	9396.65	9690.41	9171.59
t-BUTENE-2	246.92	261.05	250.12	252.44
NEOPENTANE	74.11	67.79	61.85	65.60
c-BUTENE-2	417.76	412.95	396.27	442.88
3MBUTENE-1	1070.95	1125.82	934.56	985.29
I-PENTANE	66040.79	71903.32	74931.87	71190.24
PENTENE-1	2607.94	2810.75	2861.58	2916.45
2MBUTENE-1	4302.94	4672.50	4853.12	4711.45
N-PENTANE	18356.18	20013.73	20938.81	19897.01
BUTADIENE-13	226.91	227.92	275.01	302.44
trans-PENTENE-2	5828.15	6319.27	6626.36	6349.16
33DMBUTENE-1	77.59	71.97	116.00	97.98
cis-PENTENE-2	3158.69	3408.24	3613.95	3405.58
2MBUTENE-2	6776.20	7292.79	7404.38	7311.17
UNKNOWN	73.68	70.26	609.37	70.12
1trans, 3-PENTADIENE	66.08	74.66	128.72	71.03
22DMBUTANE	6310.11	6939.16	7585.03	6889.87
C6-OLEFIN	834.18	1064.87	1051.05	877.02
CYCLOPENTENE	106.16	234.73	128.56	112.80
4M-PENTENE-1	274.71	565.89	419.60	283.74
3M-PENTENE-1	1296.94	1397.38	1534.91	1376.16
23DMBUTANE	2869.93	3118.51	3354.00	3149.79
UNKNOWN	213.31	209.04	270.95	224.08
UNKNOWN	143.55	135.44	175.66	161.69
2MPENTANE	5652.88	6147.36	6360.83	6191.10
4MtPENTENE-2	259.11	283.22	786.67	283.97
3MPENTANE	3440.98	3779.87	4048.09	3784.74
2MPENTENE-1	441.89	476.89	513.95	469.29
HEXENE-1	313.07	347.55	475.66	346.76
N-HEXANE	1967.07	2140.48	2256.44	2143.57
UNKNOWN	316.29	341.15	344.95	348.39
UNKNOWN	148.54	153.65	180.57	154.68
t-HEXENE-2	676.18	735.41	776.58	741.03
2MPENTENE-2	601.00	661.10	680.46	650.65
UNKNOWN	231.33	244.71	275.47	260.70
UNKNOWN	398.87	435.69	464.31	438.03
UNKNOWN	136.19	151.87	173.72	158.40
cis-HEXENE-2	377.96	424.79	479.78	421.11
UNKNOWN	564.00	604.54	640.77	607.23
22DMPENTANE	127.31	136.29	149.20	139.73

STRATIFICATION EXPERIMENT I (Continued)
Variables are Time and Fuel Temperature

Test Fuel	FL2407	FL2407	FL2407	FL2407
Hours out of 45 deg. Cold Box	4.00	5.75	7.75	24.00
Liquid Fuel Temperature, degs F	76.00	76.00	76.50	74.00
Room Temperature, degs F	77.50	75.70	76.10	73.80
Total Concentration, mole%	20.20	22.14	23.22	21.89
	Species Concentrations in ppm			
MCYCPENTANE	2059.66	2220.75	2328.71	2228.67
24DMPENTANE	1488.14	1622.12	1705.34	1658.08
223TMBUTANE	113.96	124.82	129.08	79.43
UNKNOWN	32.38	31.12	29.79	28.84
UNKNOWN	21.18	22.68	24.45	22.27
BENZENE	4112.77	4261.63	4441.29	4145.32
33DMPENTANE	191.08	187.50	231.94	188.56
CYCLOHEXANE	209.86	199.96	226.41	199.45
UNKNOWN	55.12	35.82	63.13	35.92
2MHEXANE	79.03	79.23	88.12	81.82
23DMPENTANE	1410.85	1533.60	1608.64	1536.76
UNKNOWN	1003.09	1070.82	1140.24	1081.37
11DMCYPENTANE	64.85	58.47	74.21	59.72
UNKNOWN	74.29	70.51	84.58	70.65
CYCLOHEXENE	1756.20	1894.01	1999.23	1900.15
3MHEXANE ?	368.68	397.08	424.80	393.04
c13DMCYPENTANE	289.22	312.56	329.97	313.44
t13DMCYPENTANE	168.07	184.70	191.89	183.44
3EPENTANE	217.85	241.77	249.47	238.24
224TMPENTANE	9404.57	10263.07	10640.99	10419.31
UNKNOWN	83.47	101.39	108.79	87.31
UNKNOWN	160.06	180.18	192.94	180.90
t-HEPTENE-3	792.28	873.79	905.62	862.39
UNKNOWN	171.29	195.08	221.07	187.65
UNKNOWN	63.45	91.21	102.51	80.39
c-HEPTENE-3	68.75	100.58	117.21	89.52
t-HEPTENE-2	0.00	61.83	89.69	41.40
UNKNOWN	133.32	158.13	185.27	145.88
UNKNOWN	64.81	97.22	106.89	102.31
UNKNOWN	187.95	206.82	209.09	204.89
UNKNOWN	396.57	425.86	441.13	423.11
McycHEXANE	18.60	45.34	39.63	45.61
22DMHEXANE	0.00	54.04	56.89	60.87
EcycPENTANE	1266.64	1367.76	1395.69	1364.53
223TMPENTANE	204.78	228.80	212.33	218.38
McycHEXENE1	1531.08	1700.57	1690.36	1624.12
1t2c4TMcycPENTANE	79.28	90.97	91.00	84.39
UNKNOWN	0.00	39.37	42.07	47.03
1t2c3TMcycPENTANE	41.08	39.80	41.79	41.91
234TMPENTANE	1529.95	1636.90	1560.27	1526.45
TOLUENE	11615.16	12128.11	12216.17	11588.66
23DMHEXANE	651.08	686.59	637.63	625.10
2MHEPTANE	364.70	382.73	388.19	386.73

STRATIFICATION EXPERIMENT I (Continued)
Variables are Time and Fuel Temperature

Test Fuel	FL2407	FL2407	FL2407	FL2407
Hours out of 45 deg. Cold Box	4.00	5.75	7.75	24.00
Liquid Fuel Temperature, degs F	76.00	76.00	76.50	74.00
Room Temperature, degs F	77.50	75.70	76.10	73.80
Total Concentration, mole%	20.20	22.14	23.22	21.89
	Species Concentrations in ppm			
4MC7	162.24	171.05	167.94	173.13
112TMcycC5	90.31	89.15	87.01	90.22
UNKNOWN	94.63	113.84	106.95	114.88
3EC6	390.27	403.93	397.30	409.48
2M3EPENTANE	152.88	137.06	120.40	162.12
34DMHexane	49.50	39.16	0.00	0.00
t14DMcycC6	43.61	42.69	0.00	53.57
UNKNOWN	219.78	227.50	231.62	237.83
UNKNOWN	69.98	69.89	88.45	88.93
1-0CTENE	49.89	56.13	56.46	60.48
N-OCTANE	212.98	222.21	235.66	221.65
UNKNOWN	0.00	65.00	73.01	66.72
33DMC7&35DMC7-I	44.53	0.00	45.48	51.64
ETHYLBENZENE	1697.85	1772.23	1783.23	1685.75
M-XYLENE	3198.41	3318.48	3360.57	3207.47
P-XYLENE	1686.23	1751.91	1762.08	1695.87
UNKNOWN	56.40	55.77	64.81	55.93
2MC8	77.00	78.85	78.67	76.42
3MOCTANE	88.40	84.86	94.56	95.70
O-XYLENE&112TMcycC6	1771.99	1817.38	1774.50	1731.32
UNKNOWN	48.66	44.93	53.76	51.41
iC3BENZENE	44.72	47.90	54.61	53.97
nC3BENZENE	244.76	221.03	282.45	290.46
1M3EBENZENE	785.43	757.78	797.04	805.47
1M4EBENZENE	340.08	386.07	360.43	384.54
23DMOCTANE	228.55	425.92	301.90	300.71
2MC9 or 3EOCTANE	241.62	253.57	249.23	248.33
3MC9	0.00	0.00	24.25	22.42
124TMBENZENE	0.00	1080.55	1134.07	1152.94
UNKNOWN	0.00	39.53	87.99	0.00
UNKNOWN	0.00	246.39	191.65	189.88
1M3iC3BENZENE	0.00	97.09	41.20	0.00
UNKNOWN	0.00	171.51	172.44	183.45
1M2iC3BENZENE	0.00	28.86	30.71	33.88
UNKNOWN	0.00	44.03	48.25	51.58
1M3nC3BENZENE	0.00	145.95	139.86	126.06
1M4nC3BENZENE	0.00	53.91	70.04	64.26
nC4BENZENE	0.00	83.91	96.47	89.90
1M2nC3BENZENE	0.00	52.98	50.74	37.56
UNKNOWN	0.00	57.08	71.03	62.90
14DM2EBENZENE	0.00	180.85	114.90	94.83
IC11	0.00	148.55	188.77	138.10
1245TMBENZENE	0.00	0.00	75.01	47.27

STRATIFICATION EXPERIMENT I (Continued)
Variables are Time and Fuel Temperature

Test Fuel	FL2407	FL2407	FL2407	FL2407
Hours out of 45 deg. Cold Box	4.00	5.75	7.75	24.00
Liquid Fuel Temperature, degs F	76.00	76.00	76.50	74.00
Room Temperature, degs F	77.50	75.70	76.10	73.80
Total Concentration, mole%	20.20	22.14	23.22	21.89
	Species Concentrations in ppm			
UNKNOWN	0.00	0.00	64.47	44.62
UNKNOWN	0.00	0.00	80.08	45.42
UNKNOWN	0.00	0.00	88.11	56.01
nC5BENZENE	0.00	0.00	32.08	0.00
t1M2(4MP)cycC5	0.00	0.00	82.02	50.53
1tC44EBENZENE	0.00	0.00	105.28	67.63
Total Concentration, ppm	201992.87	221376.06	231151.11	218900.31

STRATIFICATION EXPERIMENT II
Constant Temperature (75 degs F)

TEST FUEL	FL2408	FL2408	FL2408	FL2408	FL2408
DIFFUSION TIME, HRS	0.42	0.75	1.17	1.33	1.92
Total Concentration, mole%	4.19	10.00	14.87	17.22	21.69

Species Concentrations in ppm

Iso-BUTANE	421.86	947.93	1372.93	1586.60	1904.29
BUTENE-1	114.79	396.86	497.10	472.58	623.71
N-BUTANE	2028.82	4700.34	6590.62	7501.74	9250.33
t-BUTENE-2	68.71	138.66	270.43	298.88	338.96
NEOPENTANE	0.00	62.51	65.84	69.64	90.35
c-BUTENE-2	106.65	256.54	349.24	418.00	468.66
3M-BUTENE-1	189.70	303.52	614.03	706.19	816.45
Iso-PENTANE	17427.72	42051.68	62015.81	71938.37	91658.86
PENTADIENE-1,4	0.00	0.00	0.00	506.65	608.72
PENTENE-1	483.86	1027.29	1664.45	2054.15	2484.61
2M-BUTENE-1	800.59	1785.36	2703.29	3204.48	3965.12
N-PENTANE	5487.34	13193.77	19247.92	22639.21	28330.86
BUTADIENE-13	65.50	34.74	180.94	93.17	305.89
t-PENTENE-2	1011.47	2341.09	3589.53	4046.50	5227.19
33DM-BUTENE-1	0.00	0.00	43.19	28.58	89.35
cis-PENTENE-2	525.62	1138.27	1943.84	2184.42	2815.26
2M-BUTENE-2	1090.76	2520.67	4090.20	4470.02	5693.51
UNKNOWN	0.00	0.00	50.93	175.44	393.69
PENTADIENE-1-t,3	19.05	29.15	46.93	57.02	85.89
22DM-BUTANE	1689.59	4481.64	6873.44	8035.69	10642.46
C6-OLEFIN	173.72	349.69	523.84	602.03	765.42
CYCLOPENTENE	0.00	137.15	58.50	76.05	91.17
4M-PENTENE-1	98.38	932.72	140.50	179.77	247.91
3M-PENTENE-1	419.33	0.00	1369.27	1582.89	1998.10
23DM-BUTANE	335.68	830.17	1236.56	1454.03	1893.16
UNKNOWN	49.01	76.05	119.36	156.54	186.75
UNKNOWN	0.00	0.00	64.61	89.83	100.40
2M-PENTANE	709.85	1791.89	2652.50	3098.80	4147.82
4M-t-PENTENE-2	72.76	130.05	183.18	329.22	200.84
3M-PENTANE	414.35	1092.89	1661.16	1935.92	2484.76
2M-PENTENE-1	45.45	133.42	242.09	275.70	333.06
HEXENE-1	0.00	113.19	182.86	177.76	275.58
N-HEXANE	259.28	629.44	962.40	1098.98	1408.97
UNKNOWN	63.19	122.06	169.92	194.39	231.64
t-HEXENE-2	94.50	195.29	356.26	403.02	511.73
2M-PENTENE-2	59.62	175.14	319.96	357.49	455.75
UNKNOWN	0.00	0.00	0.00	148.98	305.04
UNKNOWN	47.59	102.82	218.81	238.81	115.48
UNKNOWN	0.00	0.00	83.38	86.78	0.00
cis-HEXENE-2	69.48	134.56	219.88	229.10	299.69
UNKNOWN	0.00	194.94	295.66	338.93	421.32
22DM-PENTANE	77.26	38.10	57.54	66.70	85.53
M-cyc-PENTANE	281.72	684.02	1040.60	1186.29	1510.52
24DM-PENTANE	141.57	350.90	561.83	647.26	816.17

STRATIFICATION EXPERIMENT II (Continued)
Constant Temperature (75 degs F)

TEST FUEL	FL2408	FL2408	FL2408	FL2408	FL2408
DIFFUSION TIME, HRS	0.42	0.75	1.17	1.33	1.92
Total Concentration, mole%	4.19	10.00	14.87	17.22	21.69
			Species Concentrations in ppm		
223TM-BUTANE	0.00	0.00	40.82	44.02	48.93
BENZENE	867.62	1750.20	2327.30	2592.79	3037.03
33DM-PENTANE	0.00	97.75	74.74	86.75	116.10
CYCLOHEXANE	35.87	74.31	90.54	114.97	129.73
UNKNOWN	0.00	0.00	0.00	39.94	27.31
2M-HEXANE	0.00	20.50	37.86	45.59	52.50
23DM-PENTANE	144.91	402.25	622.95	724.17	938.57
UNKNOWN	0.00	251.75	391.49	457.10	585.63
11DM-cyc-PENTANE	98.07	80.46	0.00	28.88	38.79
UNKNOWN	0.00	0.00	41.78	42.39	48.28
CYCLOHEXENE	193.63	497.30	794.06	892.00	1155.26
3M-HEXANE	51.88	118.36	180.18	206.72	254.80
c13DM-cyc-PENTANE	35.87	92.98	138.58	159.45	200.21
t13DM-cyc-PENTANE	0.00	48.86	82.56	93.93	116.15
3E-PENTANE	26.77	69.53	105.73	116.73	155.92
224TM-PENTANE	627.89	2023.66	3017.44	3505.07	4613.52
UNKNOWN	0.00	0.00	73.33	31.49	58.47
UNKNOWN	0.00	0.00	0.00	88.87	106.48
t-HEPTENE-3	91.42	216.80	352.84	403.54	539.98
UNKNOWN	0.00	0.00	60.43	66.03	126.50
UNKNOWN	0.00	0.00	0.00	0.00	0.00
c-HEPTENE-3	0.00	0.00	40.86	45.13	67.26
t-HEPTENE-2	0.00	0.00	0.00	0.00	42.08
UNKNOWN	0.00	56.57	69.80	82.02	119.68
UNKNOWN	0.00	0.00	0.00	52.22	74.14
UNKNOWN	27.76	62.54	89.82	102.17	128.71
UNKNOWN	51.75	125.55	190.87	214.69	268.24
M-cyc-HEXANE	0.00	0.00	0.00	0.00	15.20
22DM-HEXANE	0.00	0.00	0.00	0.00	0.00
E-cyc-PENTANE	66.41	303.91	459.66	519.86	676.77
223TM-PENTANE	0.00	0.00	0.00	0.00	0.00
M-cyc-HEXENE-1	91.17	405.56	632.70	701.21	955.61
1t2c4TM-cyc-PENTANE	0.00	38.52	36.26	41.08	46.64
1t2c3TM-cyc-PENTANE	0.00	0.00	0.00	0.00	0.00
234TM-PENTANE	107.01	333.70	480.83	548.79	700.96
TOLUENE	2035.82	4705.06	6073.44	6553.71	7649.18
23DM-HEXANE	46.88	229.25	320.67	239.55	305.32
2M-HEPTANE	31.06	110.45	163.42	188.63	223.70
4M-HEPTANE	0.00	46.44	70.34	88.15	90.83
112TMcycC5	0.00	0.00	0.00	86.68	14.90
3E-HEXANE	33.61	109.18	162.03	193.11	238.63
2M-3E-PENTANE	0.00	0.00	0.00	59.41	74.44
34DM-Hexane	0.00	0.00	0.00	0.00	0.00
UNKNOWN	0.00	0.00	78.42	76.16	98.52

STRATIFICATION EXPERIMENT II (Continued)
Constant Temperature (75 degs F)

TEST FUEL	FL2408	FL2408	FL2408	FL2408	FL2408
DIFFUSION TIME, HRS	0.42	0.75	1.17	1.33	1.92
Total Concentration, mole%	4.19	10.00	14.87	17.22	21.69
Species Concentrations in ppm					
UNKNOWN	0.00	0.00	0.00	0.00	34.83
1-0CTENE	0.00	0.00	0.00	0.00	0.00
n-OCTANE	0.00	45.67	97.42	112.95	134.53
UNKNOWN	0.00	0.00	0.00	0.00	0.00
33DM-HEPTANE	0.00	0.00	0.00	0.00	0.00
E-BENZENE	316.73	0.00	963.02	1079.16	1140.89
m-XYLENE	611.96	0.00	1773.56	1926.72	2163.67
p-XYLENE	352.65	708.11	895.18	1004.37	1086.89
UNKNOWN	0.00	0.00	0.00	0.00	25.09
2MC8	0.00	0.00	0.00	41.33	39.21
3M-OCTANE	0.00	0.00	0.00	47.73	56.46
o-XYLENE	331.51	1295.97	957.36	1095.62	1174.37
UNKNOWN	0.00	0.00	0.00	25.54	0.00
iC3-BENZENE	0.00	0.00	20.51	30.13	36.82
nC3-BENZENE	64.10	637.97	147.20	151.54	189.76
1M-3E-BENZENE	162.24	627.98	415.99	441.23	512.86
1M-4E-BENZENE	86.83	122.01	203.05	203.74	229.06
23DM-OCTANE	75.42	282.98	146.63	165.01	192.95
3E-OCTANE	39.60	152.75	137.02	147.82	156.82
3M-NONANE	0.00	0.00	0.00	0.00	0.00
124TM-BENZENE	224.91	124.94	594.72	640.82	734.36
1M-3iC3-BENZENE	48.46	119.23	110.46	114.14	123.18
Total Concentration, ppm	41924.54	100013.54	148695.19	172203.47	216853.68

STRATIFICATION EXPERIMENT II (Continued)
Constant Temperature (75 degs F)

TEST FUEL	FL2408	FL2408	FL2408	FL2408	FL2408
DIFFUSION TIME, HRS	2.63	3.50	4.58	5.00	24.00
Total Concentration, mole%	24.06	26.88	27.97	28.90	28.42

Species Concentrations in ppm

Iso-BUTANE	2027.69	2154.77	2278.11	2356.85	2212.49
BUTENE-1	557.32	394.13	556.31	524.95	452.62
N-BUTANE	9938.28	10712.04	11331.40	11460.03	10985.38
t-BUTENE-2	318.47	403.39	366.99	427.21	409.45
NEOPENTANE	102.32	109.59	157.95	118.43	119.80
c-BUTENE-2	452.50	559.16	503.34	562.78	581.37
3M-BUTENE-1	736.88	1041.07	924.20	1173.75	1112.56
Iso-PENTANE	101313.22	113832.05	119391.17	121415.54	120117.60
PENTADIENE-1,4	0.00	0.00	0.00	764.98	721.21
PENTENE-1	2437.39	2880.96	2866.76	3392.23	3279.02
2M-BUTENE-1	4264.65	4781.52	4970.79	5214.64	5143.19
N-PENTANE	31383.92	35583.39	37179.41	37561.91	37746.80
BUTADIENE-13	295.62	122.57	96.26	463.02	135.81
t-PENTENE-2	5759.22	6258.61	6481.51	6903.94	6571.44
33DM-BUTENE-1	0.00	49.84	47.47	143.59	50.79
cis-PENTENE-2	3085.95	3361.11	3407.53	3753.81	3527.20
2M-BUTENE-2	6364.64	7002.33	7286.09	7497.73	7297.20
UNKNOWN	526.71	301.76	217.44	486.90	261.38
PENTADIENE-1-t,3	115.23	72.97	67.68	130.13	69.10
22DM-BUTANE	12148.47	13595.64	14354.98	14810.19	14820.09
C6-OLEFIN	930.78	903.78	893.49	946.34	915.81
CYCLOPENTENE	101.97	120.63	96.16	121.62	119.60
4M-PENTENE-1	378.83	310.81	265.52	270.43	285.24
3M-PENTENE-1	2254.32	2499.38	2532.51	2578.56	2531.21
23DM-BUTANE	2184.46	2441.80	2537.85	2558.55	2596.72
UNKNOWN	247.83	267.19	213.39	226.89	231.40
UNKNOWN	126.45	142.72	115.44	123.44	132.39
2M-PENTANE	4607.74	5222.93	5592.46	5516.53	5711.11
4M-t-PENTENE-2	585.52	602.78	259.51	382.51	287.14
3M-PENTANE	2994.72	3280.32	3385.59	3460.49	3480.61
2M-PENTENE-1	390.15	451.28	418.34	464.66	467.63
HEXENE-1	461.17	377.52	367.35	320.95	342.25
N-HEXANE	1601.90	1803.29	1890.07	1929.54	1942.13
UNKNOWN	252.70	296.57	300.25	330.06	329.63
t-HEXENE-2	581.88	637.38	671.15	690.35	696.25
2M-PENTENE-2	509.12	572.50	614.42	615.33	624.56
UNKNOWN	0.00	220.91	245.85	248.23	240.99
UNKNOWN	356.35	376.74	414.86	407.34	415.14
UNKNOWN	138.92	118.02	177.17	144.98	143.44
cis-HEXENE-2	355.51	324.51	445.22	412.84	412.76
UNKNOWN	476.23	539.06	566.30	573.50	574.25
22DM-PENTANE	102.01	110.32	122.88	121.35	125.02
M-cyc-PENTANE	1700.39	1926.84	2013.50	2055.58	2043.83
24DM-PENTANE	957.50	1070.78	1139.15	1178.71	1202.92

STRATIFICATION EXPERIMENT II (Continued)
Constant Temperature (75 degs F)

TEST FUEL	FL2408	FL2408	FL2408	FL2408	FL2408
DIFFUSION TIME, HRS	2.63	3.50	4.58	5.00	24.00
Total Concentration, mole%	24.06	26.88	27.97	28.90	28.42
		Species Concentrations in ppm			
223TM-BUTANE	57.95	62.89	96.19	65.75	93.56
BENZENE	3414.64	3764.82	3861.93	3989.81	3742.45
33DM-PENTANE	140.62	166.46	168.33	168.30	170.48
CYCLOHEXANE	152.81	174.03	179.62	180.96	188.29
UNKNOWN	26.86	33.33	28.29	35.58	35.10
2M-HEXANE	50.39	64.96	63.81	77.09	73.37
23DM-PENTANE	1056.58	1209.36	1274.49	1315.25	1324.13
UNKNOWN	666.43	766.15	810.72	822.88	835.41
11DM-cyc-PENTANE	41.67	46.96	52.02	45.50	45.64
UNKNOWN	49.13	62.55	57.54	68.85	65.71
CYCLOHEXENE	1316.10	1502.52	1571.88	1643.34	1645.91
3M-HEXANE	286.83	320.83	338.99	354.05	349.71
c13DM-cyc-PENTANE	226.88	254.06	264.85	278.97	279.27
t13DM-cyc-PENTANE	126.03	149.00	151.55	165.63	161.86
3E-PENTANE	172.14	197.32	201.36	212.08	214.35
224TM-PENTANE	5402.58	6138.33	6567.35	6785.67	6945.18
UNKNOWN	35.93	59.14	42.28	83.88	53.85
UNKNOWN	109.13	146.05	130.68	161.86	148.29
t-HEPTENE-3	605.00	688.24	704.36	751.39	734.52
UNKNOWN	117.61	158.33	142.86	168.37	166.54
UNKNOWN	51.65	71.84	57.28	70.95	72.68
c-HEPTENE-3	50.02	78.49	53.51	85.58	84.12
t-HEPTENE-2	0.00	42.65	0.00	46.73	55.21
UNKNOWN	113.57	139.70	125.72	138.14	119.88
UNKNOWN	70.41	79.88	0.00	59.25	53.41
UNKNOWN	147.03	163.83	170.11	184.97	177.88
UNKNOWN	299.80	335.39	357.75	364.57	361.89
M-cyc-HEXANE	15.54	18.49	17.20	15.64	40.25
22DM-HEXANE	0.00	0.00	0.00	0.00	56.12
E-cyc-PENTANE	776.23	874.26	908.64	958.08	965.92
223TM-PENTANE	0.00	0.00	0.00	0.00	0.00
M-cyc-HEXENE-1	1048.72	1207.09	1221.19	1337.86	1319.85
1t2c4TM-cyc-PENTANE	58.99	66.34	73.77	81.57	78.12
1t2c3TM-cyc-PENTANE	21.54	25.55	0.00	35.40	37.15
234TM-PENTANE	823.11	918.36	981.04	1005.89	1012.99
TOLUENE	8630.93	9296.00	9600.99	10161.37	9298.18
23DM-HEXANE	356.75	401.85	419.48	432.13	434.75
2M-HEPTANE	245.22	284.51	294.30	310.04	30.73
4M-HEPTANE	102.26	118.80	121.71	123.04	313.07
112TMcycC5	0.00	24.12	24.04	24.78	127.61
3E-HEXANE	269.36	316.31	331.30	342.70	334.03
2M-3E-PENTANE	84.29	120.34	131.86	107.39	102.94
34DM-Hexane	0.00	34.09	0.00	0.00	156.59
UNKNOWN	135.36	135.45	146.74	147.57	0.00
UNKNOWN	76.72	74.11	68.20	0.00	81.15

STRATIFICATION EXPERIMENT II (Continued)
Constant Temperature (75 degs F)

TEST FUEL	FL2408	FL2408	FL2408	FL2408	FL2408
DIFFUSION TIME, HRS	2.63	3.50	4.58	5.00	24.00
Total Concentration, mole%	24.06	26.88	27.97	28.90	28.42
	Species Concentrations in ppm				
1-0CTENE	50.99	39.59	50.48	43.34	55.42
n-OCTANE	142.94	169.33	180.76	189.34	198.82
UNKNOWN	0.00	53.92	48.52	59.23	58.65
33DM-HEPTANE	33.61	0.00	0.00	32.95	51.72
E-BENZENE	1264.56	1409.84	1474.17	1506.23	1375.34
m-XYLENE	2374.66	2662.19	2614.00	2827.38	2677.26
p-XYLENE	1237.96	1379.02	1329.12	1480.13	1386.69
UNKNOWN	45.11	41.67	42.97	48.52	33.98
2MC8	58.31	58.02	62.04	59.15	51.75
3M-OCTANE	70.92	84.78	72.61	75.20	70.63
o-XYLENE	1301.66	1503.37	1400.52	1596.30	1457.68
UNKNOWN	29.56	40.54	39.98	27.18	40.48
iC3-BENZENE	36.93	46.76	44.30	37.32	55.38
nC3-BENZENE	190.84	240.22	225.47	237.41	226.52
1M-3E-BENZENE	565.91	632.94	593.90	644.05	636.62
1M-4E-BENZENE	250.15	287.63	230.86	279.02	289.30
23DM-OCTANE	221.89	222.93	251.71	237.19	220.25
3E-OCTANE	177.48	197.21	188.12	212.25	208.37
3M-NONANE	0.00	0.00	104.53	0.00	16.45
124TM-BENZENE	825.64	933.61	906.94	964.72	891.77
1M-3iC3-BENZENE	149.71	168.67	226.67	170.83	156.01
Total Concentration, ppm	240586.58	268800.02	279665.43	288978.04	284213.77

APPENDIX H

Fuel Tank Test

FUEL TANK TEST
EPA Diurnal Cycle (60 to 84 degs F)
Test Fuel: FL2408B

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Test Cell Temperature, F	80.00	84.00	81.64	74.25	69.30	67.20
Fuel Temperature, F	78.26	81.50	81.50	77.00	71.06	67.46
Vapor Temperature, F	78.08	82.04	80.42	75.20	69.26	66.20
Fuel Vapor Conc., mole %	36.55	35.16	34.99	33.54	24.33	27.10

Species Concentrations in ppm

SPECIES NAME	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Iso-BUTANE	2081.91	2127.51	2098.00	2042.18	1552.09	1770.92
METHANOL	13016.48	14001.52	13406.62	13609.68	10129.25	11293.58
BUTENE-1	1494.39	1552.41	1478.47	1445.93	1113.38	1213.03
N-BUTANE	10494.88	10835.08	10460.61	10257.88	7740.04	8612.20
t-BUTENE-2	407.61	420.91	402.62	371.09	271.80	306.89
NEOPENTANE	105.74	113.25	121.37	105.17	86.08	97.81
c-BUTENE-2	549.89	597.99	512.24	545.91	400.72	402.68
3M-BUTENE-1	1096.55	1079.55	1031.95	986.53	739.78	838.07
Iso-PENTANE	119649.07	119399.58	115656.01	110355.59	80059.08	90092.90
PENTADIENE-1,4	1329.22	1504.25	1463.69	1438.79	1203.05	1196.83
PENTENE-1	3379.83	3384.11	3044.91	2917.59	2206.32	2347.22
2M-BUTENE-1	5187.33	5199.30	4813.45	4587.46	3359.02	3680.22
N-PENTANE	37775.73	37387.58	36237.32	34708.13	24819.24	27812.69
BUTADIENE-13	450.91	443.84	314.68	308.56	340.39	244.84
t-PENTENE-2	6922.95	6889.41	6354.24	6090.48	4465.60	4827.61
UNKNOWN	155.74	155.98	78.98	89.67	116.71	72.41
33DM-BUTENE-1	3028.65	2992.46	2740.28	2628.08	1924.86	2076.13
cis-PENTENE-2	1270.52	1293.19	1140.88	1136.94	697.50	766.95
2M-BUTENE-2	8062.26	8001.49	7540.06	7289.75	5290.94	5768.15
UNKNOWN	1246.77	1222.40	754.55	793.98	1025.20	673.27
PENTADIENE-1-t,3	226.40	241.30	93.77	99.61	145.84	87.11
22DM-BUTANE	16026.20	15391.81	14690.47	14256.60	10235.55	11116.27
C6-OLEFIN	1285.34	1248.17	873.97	861.10	740.71	667.71
CYCLOPENTENE	213.20	210.19	103.34	110.21	93.91	70.64
4M-PENTENE-1	563.39	495.42	291.97	297.31	255.75	229.18
3M-PENTENE-1	2859.96	2794.83	2538.53	2514.15	1768.29	1926.52
23DM-BUTANE	2230.27	2080.62	2058.53	2062.76	1444.84	1577.79
MTBE	65783.06	63439.93	66626.27	62460.04	45459.09	47441.54
2M-PENTANE	6501.73	6083.38	5354.76	6172.22	3494.18	4750.30
4M-t-PENTENE-2	1590.65	1920.98	264.26	1424.26	165.76	1250.70
UNKNOWN	367.36	468.47	145.73	286.63	107.72	221.35
3M-PENTANE	4120.74	3882.13	3463.46	3705.08	2301.29	2789.36
2M-PENTENE-1	610.70	593.64	449.34	495.22	286.43	359.75
HEXENE-1	751.68	846.57	302.62	474.87	211.13	336.35
N-HEXANE	2195.51	2011.30	1930.65	1969.77	1265.14	1455.73
UNKNOWN	395.86	379.19	313.63	319.06	202.23	228.59
t-HEXENE-2	806.39	755.24	659.75	687.90	436.94	494.07
2M-PENTENE-2	706.19	648.11	590.59	610.78	390.31	447.48
UNKNOWN	285.76	290.35	228.47	238.25	156.30	160.46
UNKNOWN	476.39	439.57	395.82	410.39	266.80	294.27
UNKNOWN	210.38	221.78	122.93	140.07	96.60	89.59

FUEL TANK TEST (Continued)
EPA Diurnal Cycle (60 to 84 degs F)
Test Fuel: FL2408B

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Test Cell Temperature, F	80.00	84.00	81.64	74.25	69.30	67.20
Fuel Temperature, F	78.26	81.50	81.50	77.00	71.06	67.46
Vapor Temperature, F	78.08	82.04	80.42	75.20	69.26	66.20
Fuel Vapor Conc., mole %	36.55	35.16	34.99	33.54	24.33	27.10
Species Concentrations in ppm						
cis-HEXENE-2	550.45	568.90	348.70	395.34	266.20	249.77
UNKNOWN	669.90	619.63	550.90	564.63	370.68	426.03
22DM-PENTANE	154.31	147.05	130.17	124.89	83.79	99.42
M-cyc-PENTANE	2234.84	1995.77	2060.02	2049.01	1367.92	1558.39
24DM-PENTANE	1299.89	1095.36	1203.60	1180.14	776.57	893.94
223TM-BUTANE	77.90	78.21	92.07	75.25	54.31	63.81
BENZENE	3514.92	3201.25	3303.51	3269.90	2419.11	2660.45
33DM-PENTANE	173.68	147.97	157.06	155.50	112.94	126.66
CYCLOHEXANE	203.17	173.95	183.81	178.43	126.65	137.29
UNKNOWN	39.02	59.01	33.84	61.22	18.73	32.01
2M-HEXANE	78.24	64.66	71.02	67.93	42.05	51.07
23DM-PENTANE	1397.64	1056.41	1319.44	1232.07	869.83	1025.97
UNKNOWN	880.89	677.97	837.59	791.82	559.62	656.65
11DM-cyc-PENTANE	49.34	42.15	45.00	41.09	34.04	35.26
UNKNOWN	69.66	58.49	55.33	51.45	41.16	48.38
CYCLOHEXENE	1716.85	1260.28	1621.88	1473.78	1081.58	1281.31
3M-HEXANE	367.59	279.44	350.93	315.10	236.99	271.80
c13DM-cyc-PENTANE	295.19	223.96	276.46	256.20	190.60	217.28
t13DM-cyc-PENTANE	171.40	129.80	159.52	142.89	108.21	121.99
3E-PENTANE	228.03	173.23	207.36	191.45	142.96	158.60
224TM-PENTANE	7074.01	4893.13	6726.32	5996.50	4493.39	5370.06
UNKNOWN	67.49	36.04	63.66	52.63	42.72	29.18
UNKNOWN	158.98	116.08	144.11	125.59	85.65	101.97
t-HEPTENE-3	743.55	521.05	725.87	634.42	452.98	546.36
N-HEPTANE	172.79	114.83	158.47	132.03	62.13	77.33
UNKNOWN	65.46	50.90	65.76	58.50	0.00	0.00
c-HEPTENE-3	80.59	57.99	73.74	62.34	40.99	44.59
t-HEPTENE-2	44.59	34.54	57.79	29.76	0.00	0.00
UNKNOWN	163.32	122.09	149.98	132.03	112.42	122.09
UNKNOWN	81.61	43.43	60.77	71.87	0.00	0.00
UNKNOWN	185.68	133.56	178.28	153.17	123.99	143.20
UNKNOWN	393.35	272.01	351.78	311.40	254.77	290.36
M-cyc-HEXANE	39.43	12.42	17.48	40.86	0.00	0.00
22DM-HEXANE	43.17	0.00	0.00	0.00	0.00	0.00
E-cyc-PENTANE	930.76	571.00	882.78	735.88	594.14	740.40
223TM-PENTANE	1070.00	649.89	1011.51	853.04	694.58	860.14
1t2c4TM-cyc-PENTANE	76.36	49.32	71.96	54.85	46.44	61.34
1t2c3TM-cyc-PENTANE	32.54	25.82	36.92	0.00	0.00	24.36
234TM-PENTANE	977.81	555.86	919.85	738.08	608.23	785.23
TOLUENE	8026.57	5441.49	7926.50	6554.77	5702.36	6956.69
23DM-HEXANE	432.58	226.90	385.61	308.97	247.48	325.24
2M-HEPTANE	277.59	132.69	266.25	206.06	175.60	223.49

FUEL TANK TEST (Continued)
EPA Diurnal Cycle (60 to 84 degs F)
Test Fuel: FL2408B

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Test Cell Temperature, F	80.00	84.00	81.64	74.25	69.30	67.20
Fuel Temperature, F	78.26	81.50	81.50	77.00	71.06	67.46
Vapor Temperature, F	78.08	82.04	80.42	75.20	69.26	66.20
Fuel Vapor Conc., mole %	36.55	35.16	34.99	33.54	24.33	27.10
Species Concentrations in ppm						
4M-HEPTANE	112.74	56.44	110.96	80.17	70.81	95.28
112TMcycC5	20.64	14.34	21.83	0.00	0.00	18.98
3E-HEXANE	296.03	150.74	287.62	223.55	181.74	241.99
2M-3E-PENTANE	92.85	51.31	90.14	71.44	62.44	78.74
UNKNOWN	153.06	67.25	147.42	96.62	64.49	104.99
1-0CTENE	45.10	0.00	0.00	36.29	0.00	0.00
n-OCTANE	146.68	71.29	160.54	101.90	81.92	112.68
E-BENZENE	731.85	393.29	909.96	649.42	559.93	704.13
m-XYLENE	1192.57	696.52	1650.95	1178.20	1041.68	1156.61
p-XYLENE	544.60	324.34	796.41	621.66	546.96	588.30
3M-OCTANE	37.21	0.00	53.76	29.70	0.00	0.00
o-XYLENE	541.06	320.27	802.69	579.40	520.85	544.83
nC3-BENZENE	51.94	34.49	63.70	64.44	66.34	60.32
1M-4E-BENZENE	162.77	89.95	151.22	165.23	157.48	148.73
23DM-OCTANE	27.20	33.92	61.78	75.18	75.45	71.23
3E-OCTANE	24.30	33.18	50.24	55.72	54.31	59.14
124TM-BENZENE	88.52	103.88	122.20	149.82	131.50	143.37
Total Vapor Conc., ppm	365493.81	351600.52	349914.82	335355.24	243323.57	271036.58

FUEL TANK TEST (Continued)
EPA Diurnal Cycle (60 to 84 degs F)
Test Fuel: FL2408B

	Sample 7	Sample 8	Sample 9	Sample 10	Sample 11	Sample 12
Test Cell Temperature, F	66.40	60.00	66.40	76.10	82.40	84.00
Fuel Temperature, F	66.20	62.24	62.42	69.08	76.82	80.78
Vapor Temperature, F	65.48	60.80	63.86	72.14	79.52	81.68
Fuel Vapor Conc., mole %	27.68	23.85	24.21	24.70	31.64	34.45

Species Concentrations in ppm

SPECIES NAME						
Iso-BUTANE	1733.81	1611.24	1596.81	1551.20	1948.71	2047.76
METHANOL	11671.84	11661.31	10943.16	10329.92	12589.32	13508.15
BUTENE-1	1210.83	1126.09	1106.50	1080.72	1329.60	1374.43
N-BUTANE	8561.19	7799.60	7841.23	7701.50	9585.49	10176.05
t-BUTENE-2	299.53	298.46	274.35	271.44	348.52	377.98
NEOPENTANE	92.54	90.83	101.33	88.69	105.36	100.23
c-BUTENE-2	452.68	391.58	367.53	401.26	462.00	504.76
3M-BUTENE-1	773.56	786.90	678.87	663.96	905.72	978.36
Iso-PENTANE	89075.71	79459.73	80759.71	79645.94	101881.56	114635.48
PENTADIENE-1,4	1157.44	1218.05	976.52	1092.07	1311.63	1579.86
PENTENE-1	2329.98	2205.46	1979.52	2056.67	2772.31	3053.84
2M-BUTENE-1	3661.03	3330.47	3212.09	3248.24	4261.37	4788.13
N-PENTANE	27806.51	24481.73	24832.83	24668.70	31731.98	35999.52
BUTADIENE-13	241.16	364.14	71.80	192.17	405.30	382.26
t-PENTENE-2	4849.51	4449.55	4164.08	4243.37	5678.50	6354.95
UNKNOWN	0.00	136.66	0.00	49.76	159.94	131.00
33DM-BUTENE-1	2083.61	1937.49	1752.69	1837.21	2467.71	2741.98
cis-PENTENE-2	848.62	745.67	482.05	650.70	1163.49	1372.09
2M-BUTENE-2	5802.73	5179.58	4782.71	5089.75	6626.60	7452.79
UNKNOWN	619.63	655.55	0.00	467.90	1166.91	987.95
PENTADIENE-1-t,3	85.51	191.07	52.50	52.64	208.71	168.62
22DM-BUTANE	11318.58	9979.01	9897.33	9843.73	13190.83	14821.79
C6-OLEFIN	684.10	860.59	593.76	597.83	1050.30	973.69
CYCLOPENTENE	84.45	138.75	62.70	73.65	147.57	133.68
4M-PENTENE-1	224.91	327.28	177.87	195.33	359.11	343.67
3M-PENTENE-1	1973.71	1799.32	1705.85	1723.79	2364.89	2558.05
23DM-BUTANE	1599.05	1402.76	1372.00	1392.58	1817.46	1982.75
MTBE	51605.78	40219.36	43373.44	44817.10	54412.08	65479.19
2M-PENTANE	4166.27	4024.30	3539.24	3576.14	5468.54	5240.27
4M-t-PENTENE-2	196.16	1276.00	168.97	166.99	1722.17	254.24
UNKNOWN	125.30	290.35	113.74	109.47	359.91	151.04
3M-PENTANE	2728.47	2527.12	2299.79	2332.65	3368.01	3386.58
2M-PENTENE-1	345.18	360.10	287.54	298.90	486.11	434.37
HEXENE-1	247.91	435.96	209.82	203.80	638.41	294.07
N-HEXANE	1523.27	1268.27	1283.75	1295.47	1775.89	1876.33
UNKNOWN	229.19	220.79	196.09	203.61	314.66	303.54
t-HEXENE-2	490.47	449.73	444.15	447.36	632.95	637.66
2M-PENTENE-2	343.08	388.41	393.83	392.68	546.09	582.71
UNKNOWN	0.00	154.05	153.69	156.82	239.01	0.00
UNKNOWN	275.51	250.72	264.86	265.81	380.22	382.01
UNKNOWN	74.15	91.97	90.31	91.77	166.67	123.56

FUEL TANK TEST (Continued)
EPA Diurnal Cycle (60 to 84 degs F)
Test Fuel: FL2408B

	Sample 7	Sample 8	Sample 9	Sample 10	Sample 11	Sample 12
Test Cell Temperature, F	66.40	60.00	66.40	76.10	82.40	84.00
Fuel Temperature, F	66.20	62.24	62.42	69.08	76.82	80.78
Vapor Temperature, F	65.48	60.80	63.86	72.14	79.52	81.68
Fuel Vapor Conc., mole %	27.68	23.85	24.21	24.70	31.64	34.45
Species Concentrations in ppm						
cis-HEXENE-2	277.60	219.48	269.68	252.86	375.27	355.55
UNKNOWN	439.29	343.80	385.85	366.56	515.42	548.32
22DM-PENTANE	105.62	78.41	86.21	86.65	136.12	122.74
M-cyc-PENTANE	1648.69	1271.68	1367.17	1374.38	1812.90	2008.79
24DM-PENTANE	973.78	729.07	807.79	804.52	1047.56	1160.80
223TM-BUTANE	63.60	42.59	47.63	64.42	64.25	72.08
BENZENE	2802.42	2306.99	2374.45	2289.73	2928.08	3297.50
33DM-PENTANE	134.66	94.59	111.44	104.94	145.96	148.11
CYCLOHEXANE	153.13	112.95	121.82	121.26	154.48	174.83
UNKNOWN	25.09	22.47	23.49	21.18	29.32	32.18
2M-HEXANE	60.20	43.31	48.55	51.28	57.75	70.07
23DM-PENTANE	1118.89	759.75	926.31	919.78	1140.51	1231.56
UNKNOWN	703.30	490.91	570.48	585.70	719.44	788.08
11DM-cyc-PENTANE	40.89	35.22	0.00	30.34	38.41	47.68
UNKNOWN	48.93	38.17	43.55	41.27	56.18	57.64
CYCLOHEXENE	1383.92	935.03	1163.61	1146.47	1418.80	1514.88
3M-HEXANE	296.50	203.66	249.85	243.77	301.97	334.41
c13DM-cyc-PENTANE	232.72	165.83	196.81	198.71	242.93	260.41
t13DM-cyc-PENTANE	133.73	98.85	114.22	116.80	142.83	150.39
3E-PENTANE	182.39	124.80	153.75	147.06	180.29	196.10
224TM-PENTANE	5918.23	3810.18	5051.44	5122.49	6058.08	6122.42
UNKNOWN	58.50	39.43	51.03	42.76	27.86	61.45
UNKNOWN	119.61	82.59	93.76	97.76	128.57	138.51
t-HEPTENE-3	627.50	410.09	512.97	539.78	641.11	654.17
N-HEPTANE	138.45	80.76	73.16	108.89	135.83	142.86
UNKNOWN	62.78	37.05	0.00	43.13	51.37	65.52
c-HEPTENE-3	67.36	37.77	41.47	45.40	54.67	74.01
t-HEPTENE-2	40.69	0.00	0.00	0.00	0.00	48.05
UNKNOWN	141.23	73.09	110.38	100.20	141.57	133.56
UNKNOWN	80.69	0.00	45.40	37.97	85.92	48.83
UNKNOWN	165.25	98.51	132.78	135.32	163.35	159.45
UNKNOWN	326.26	215.98	271.90	274.99	326.81	324.70
M-cyc-HEXANE	36.95	11.54	16.25	0.00	32.14	33.83
22DM-HEXANE	42.93	0.00	0.00	0.00	42.55	53.77
E-cyc-PENTANE	842.77	502.15	734.86	784.34	890.08	769.37
223TM-PENTANE	988.02	571.00	866.52	903.90	1034.49	877.57
1t2c4TM-cyc-PENTANE	60.98	40.37	55.54	54.79	59.23	59.11
1t2c3TM-cyc-PENTANE	32.16	0.00	31.74	38.17	33.70	21.72
234TM-PENTANE	902.36	535.52	808.00	883.36	985.08	794.93
TOLUENE	7403.58	5186.35	6516.46	7046.61	7980.83	7127.37
23DM-HEXANE	386.47	226.61	344.33	399.23	435.34	334.57
2M-HEPTANE	280.08	160.13	237.41	295.88	327.05	233.08

FUEL TANK TEST (Continued)
EPA Diurnal Cycle (60 to 84 degs F)
Test Fuel: FL2408B

	Sample 7	Sample 8	Sample 9	Sample 10	Sample 11	Sample 12
Test Cell Temperature, F	66.40	60.00	66.40	76.10	82.40	84.00
Fuel Temperature, F	66.20	62.24	62.42	69.08	76.82	80.78
Vapor Temperature, F	65.48	60.80	63.86	72.14	79.52	81.68
Fuel Vapor Conc., mole %	27.68	23.85	24.21	24.70	31.64	34.45
		Species Concentrations in ppm				
4M-HEPTANE	114.46	68.14	99.88	121.56	133.67	104.48
112TMcycC5	21.98	12.14	18.35	23.50	22.99	110.48
3E-HEXANE	295.34	167.64	248.93	332.37	359.92	248.64
2M-3E-PENTANE	91.57	0.00	74.17	121.17	110.27	77.79
UNKNOWN	137.35	76.87	107.57	165.38	183.14	110.57
1-0CTENE	43.67	28.32	29.90	44.23	54.17	37.75
n-OCTANE	156.39	85.90	119.60	203.68	239.43	127.05
E-BENZENE	987.11	634.11	684.93	1226.01	1356.93	816.11
m-XYLENE	1664.96	1145.11	1277.65	2319.24	2707.38	1512.86
p-XYLENE	836.20	579.87	623.34	1131.63	1356.52	754.97
3M-OCTANE	0.00	0.00	46.43	70.05	90.12	48.36
o-XYLENE	684.10	517.17	600.01	1094.74	1383.42	676.43
nC3-BENZENE	61.88	42.05	49.14	89.53	121.30	62.83
1M-4E-BENZENE	181.11	118.10	136.36	198.61	243.33	119.13
23DM-OCTANE	77.42	54.24	55.60	84.32	106.89	51.74
3E-OCTANE	64.16	44.20	52.96	74.11	60.33	26.68
124TM-BENZENE	199.99	144.56	183.60	189.62	151.32	71.66
Total Vapor Conc., ppm	276758.83	238541.11	242071.48	246981.70	316376.85	344483.91

144pp

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