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A Survey of Aviation Gasoline Properties Based on Certificate of Analysis Data

Final Report

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COORDINATING RESEARCH COUNCIL, INC.

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A Survey of Aviation Gasoline Properties Based on Certificate of Analysis Data

Prepared by M. Thom for the Coordinating Research Council, Inc., Contract No. AV-30-22

Abstract

In 2010, data were provided in support of FAA work to review the measured properties of the 100LL aviation gasoline being produced in the U.S. market. The findings were published as an FAA Technical Note, DOT/FAA/AR-TN11/20. Data evaluated during the FAA study included Certificate of Analysis (CoA) information on lead content, MON, and Supercharge rating, these values versus lead content, and aromatic concentration versus lead. That analysis was used to evaluate the range of fuels that met ASTM D910 requirements with less than the 0.56 gPb/L maximum allowable 100LL lead content. Efforts to reduce the amount of lead within the aviation piston engine community continued unabated and it was desirable to understand the current situation both here and, if possible, outside of the U.S.. Recognizing the likelihood of policy pressures to further reduce the lead emissions from the market, it was desirable to have an idea of the trend towards 100VLL production where lead concentration is limited to 0.45 gPb/L maximum. In addition to the continuation of the lead review, it was also deemed useful to evaluate how other fuel properties may have changed overtime. This document covers the analyses and presentation of aviation gasoline data provided as blinded CoAs for contemporary review, as a comparison to the original 2010 study with respect to lead, and as a review of other available properties over time. While efforts were made to comply with typical blinding requirements for petroleum data, the global production quantities of aviation gasoline are below the minimums for full compliance. These data are presented with a good faith effort to meet such blinding requirements to the greatest extent possible.

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List of Acronyms

Acronym	Definition
ASTM	ASTM International, formerly known as the American Society for Testing and Materials
AvGas	Aviation Gasoline
Bbls	Petroleum barrels (42 U.S. Gallons)
CoA	Certificate of Analysis
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FBO	Fixed Based Operator
g/L	grams per liter
gPb/L	grams of Lead per liter
gPb/gal	grams of Lead per gallon
MON	Motor Octane Number
NEG	National Exchange Group
SCR	Supercharge Rating
RVP	Reid Vapor Pressure
RoW	"Rest of the World" as opposed to the U.S. supplied data
TEL	Tetraethyl Lead
LL	Low Lead
ULL	Ultra Low Lead
VLL	Very Low Lead

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Executive Summary

Survey data consisted of blinded data downloads and Certificate of Analyses (CoA), used without change or prejudice. CoAs are accepted by the industry as a certificate of validation. Further investigations or verification of the accuracy of the reported data were determined to be outside the scope of the researcher's authority. Although MON was of interest, the primary objective of the survey was to explore and investigate lead content trends in production Aviation Gasoline (AvGas) while offering an insight into the variance in other specification properties where possible.

A second target was to consider how the reported fuel properties may have changed over time. It was determined much of the new data did not include overt dates and could only be placed in reference to the dated data received during the original FAA analysis. To help support this approach data from a U.S. Department of the Interior Bureau of Mines 1960 Grade 100/130 AvGas survey was also used.

1. The sample sets were blinded prior to receipt to help ensure anonymity.
2. A total of 125 individual Certificates of Analysis (CoA) were received in the original data pool. Of that original set, 13 were identified as being UL91 AvGas and were not included in the following analyses except as noted. The original pool had 60 CoA's which were identified as being from the U.S. and 52 from the "rest of the world". There were indications that some of the 100 octane avgas samples were produced specifically as 100VLL, but all of the samples were combined for the current analyses and no further considerations were made related to the two maximum levels of lead.
3. The original data included source information, specifically U.S. production versus the rest of the world. To meet blinding requirements, this information has been removed and the report is presented as a global review. The original FAA data were provided as U.S. production only, and as such changes reported are only from U.S. to global production.

In reviewing the data specific to the lead content and the MON values, the following two items were considered. First, given a maximum 100LL lead content of 0.56 gPb/L and a maximum 100VLL lead content of 0.45 gPb/L, what percentage of the data set would be compliant with VLL requirements. Where the data suggested that the fuel was 100LL, an analysis was made to determine what percentage of the data would be between 0.45 gPb/L (VLL maximum) and 0.51 gPb/L (a ten percent reduction over maximum lead content).

The second analysis was to determine the percentage breakdown of the reported MON value by individual MON values (104, 103, 102, 101, 100). This was done to facilitate considering if, or how much, octane margin has been relinquished over time.

The minimum and maximum reported value for each lead content and MON value are also provided as well as any special observations.

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1 *Data Analysis Summary, Lead and MON*

The data provided were from refineries from within the U.S. and "The Rest of the World". However, due to the necessary blinding requirements, there were not enough individual data sources nor enough individual certificates of analysis to permit data reviews with that level of granularity. In order to meet petroleum industry requirements, all of the data with the exception of those clearly UL91 were combined into a single data set. It was recognized that this still did not entirely meet the typical blinding requirements, however, the production quantities of AvGas at a global level are too small to facilitate full compliance.

The analyses included the average for the data (mean), the maximum, and the minimum. The properties included: the motor octane value (MON), the aviation lean rating (ALR) where provided, the supercharge rating (SCR) where provided, the lead content in g Pb/L (converted from mL TEL/L when required), and vapor pressure where provided. The lead analysis includes a review of "what percent of the maximum specified lead concentration does each statistical value represent"?

The final analysis includes the number of lead values which are above or below a target lead content value. The "what percent of" the sample set this target represents is reported.

1.1 A summary review of the global fuel samples

Table 1 - Summary of Lead and MON values

	Lead (gPb/L)					MON Value			MON Margin			
	Min	Max	Mean	% <0.45 gPb/L	% <0.51 gPb/L	Min	Max	Mean	%>101	%>102	%>103	%>104
Result	0.31	0.56	0.48	37.5%	79.2%	100.0	105.0	102.4	90	63	29	7

1.1.1 A summary of Global leaded AvGas Quality

In addition to the review of lead content versus MON values and supercharge ratings, it was also desirous to review remaining reported properties over time. Note that a set of FAA Study data were excluded here due to questionable data source and a significantly skewed distillation profile. These were data provided from an engine program and were not original certificate of analysis data.

Combining all the data provided the following overview of global leaded AvGas quality.

Table 2 - Analysis of Global AvGas Properties

		2024 Data			All Data (incl FAA Study)		
Property	Units	Min	Mean	Max	Min	Mean	Max
MON	ON	100.6	102.4	105.0	100.0	103.05	108.0
Aviation Lean	Rating	102.7	107.2	114.4	101.8	108.29	135.2
Supercharge	PN	131.1	135.0	141	113.6	133.76	141.0
Lead	gPb/L	0.32	0.5	0.56	0.08	0.46	0.56
Sulfur	% m/m	<0.00001	-	<0.01	<0.00001	-	<0.1
Vapor Pressure @38C	kPa	42.4	44.8	48.9	38.6	43.67	49.0
Density	kg/m³	700.6	711.4	728.2	692.0	705.65	728.19
IBP	°C	27.8	34.2	38.0	30.6	38.62	66.6
T10%	°C	58.7	67.1	73.3	65.4	71.5	98.1
T40%	°C	69.9	95.9	101.1	89.4	96.5	102.4
T50%	°C	93.9	100.5	105.0	95.0	101.0	116.4
T90%	°C	104.4	110.4	127.9	102.0	110.8	153.9
FBP	°C	117.0	130.4	153.8	115.0	132.1	186.7
T10% +T50%	°C	159.6	179.8	195.6	98.6	179.3	196.1
Residue	% v/v	0.5	1.0	1.5	0.1	0.9	1.5
Loss	% v/v	0.1	0.9	1.5	0.0	0.9	1.6
Net Heat	MJ/kg	43.6	44.0	44.5	43.5	44.0	44.5
Freeze	°C	<-72.0	<-66.5	<-60.6	<-80.0	<-68.8	<-53.3
Copper Corrosion	Rating	1	1A	1B	1	1A	1B
Potential Gum (5 hr Ox Stab test)	mg/100ml	0.0	0.8	2.0	0.0	0.7	3.6
Lead Ppt	mg/100ml	0.0	0.0	0.0	0.0	0.1	0.7
Water Reaction	mL	0.0	0.1	1.0	-1.0	0.2	1.0
Existent Gum	mg/100ml	0.0	0.0	0.0	0.5	1.0	1.0

1.2 MON and Lead Comparison to 2010

A review of U.S. MON data suggests there has been a measurable drop in the finished MON values in U.S. produced fuels since the 2010 data analyses. However, it is not possible to determine whether this is related to the sample populations and regionality, or to actual production shifts.

Table 3 - Percent of Data vs MON Value

2024 all Data	2010 U.S. Data		MON
7%	0%	less than	101
90%	96%	greater than	101
63%	95%	greater than	102
29%	85%	greater than	103
7%	49%	greater than	104

1.2.1 Aromatic Content Summary

There was no aromatic content data provided in any of the 2024 data sets as it was not a required reported value. However, to provide information on aromatic content, estimated values were determined for the 2024 data.

The aromatic concentration of the fuel samples was estimated using ASTM D3338, which is based on distillation, density and sulfur data. D3338 is a correlation method compared to bomb calorimeter determination of AvGas energy content and, where used, reversing the calculation provides a reasonable calculation of the concentration of aromatics in the fuel. When D3338 is actually used to provide the AvGas energy content as for many of the CoAs, the calculation gives the true, measured aromatic concentration.

For those entries reporting sulfur contents of "<0.01", a value of "0" was used for the estimated aromatic content calculations.

Table 4 - D3338 Calculated Estimated AvGas Aromatic Content

Min % v/v	Mean % v/v	Max % v/v
0.0	9.6	19.0

2 *Background*

In 2012 the FAA published Technical Note DOT/FAA/AR-TN11/20 providing an insight into Aviation Gasoline (AvGas) lead content and octane quality in support of industry development of a Very Low Lead grade (100VLL). Twelve years has now elapsed and, with high octane unleaded grades under development, there is renewed interest in determining the contemporary status of the production of AvGas with respect to existing lead content, octane and other fuel quality parameters. A point of interest is to better understand the ability for production of a 100VLL AvGas as envisaged by the earlier work. The new data procured represent, as best as possible, both U.S. and RoW production. These data are used to review any changes since the 2010 FAA program.

The first activity was to prepare a document which was directly a continuation in form and function as that of the original FAA Technical Note. To do this, the following steps were taken

- Perform necessary data processing from non-standard Excel spreadsheet laboratory downloads
- Perform necessary conversion processing to maintain uniform units (metric vs imperial)
- Perform necessary data input from .pdf to Excel format
- Process new data and generate a final report consistent with existing FAA Technical Note including consideration for 100VLL.

It was further requested a more general analysis covering each ASTM D910 / Defence Standard 91-090 Table 1 properties similar to the CRC project AV-18-17, The Quality of Aviation Fuel Available in the United Kingdom, Annual Survey 2014, be performed. This encompasses reporting on trends for fourteen Table 1 properties across years, by batches. This data is provided in the same CoA's and represents part of the data processing performed for the initial project. The scope of the additional effort covered:

- Process the data to provide distribution evaluation of the additional Table 1 properties, and where possible provide trending evaluation of the additional Table 1 properties by year, as continued from existing Tech Note data
- Develop a distribution profile for each CoA property, and where possible trending by year
- This trending would include data from the years collected for the FAA Technical Note

2.1 Methodology

2.1.1 Data Entry

In the original FAA study, individual certificates of analysis were procured from a variety of sources. The data were all blinded by the author, but coded such that analysis based on regionality was possible. The contemporary data were provided from both U.S. and global refinery sources. In order to meet blinding requirements for petroleum production, all of the data except for that specifically identified as 91UL were combined and for this report analyzed as global AvGas production without consideration for location.

For the purposes of this analysis, all data were entered as received without modification or correction, except as noted. Modifications made included calculations for commonality of units. Any temperatures were converted from Fahrenheit to Celsius. All of the provided lead contents were converted to a uniform unit of grams of lead per liter (gPb/L). For lead contents provided as milliliters of TEL, the conversion factor of 1mL TEL = 1.0589 g Pb was used. For those provided as lead in gallons, these values were converted to liters, 1 U.S. gallon = 3.785 liters. API gravities were converted to density at 15 °C in kg/m^3 using the formula density $kg/m^3 = (141.5/(API+131.5))*1000$. In cases where calculations required numerical values and only "< " or ">" reports were provided, these data were modified to the reported value, i.e. sulfur reported as <0.01 was entered as a numeric "0" for calculations.

All data were received from the CRC as either .pdf files or as Excel spreadsheets. The data were manually entered into single spreadsheets organized in the same structure as was used for the original 2010 analyses. This was done to permit the data to be more easily analyzed across both data sets when reviewing trend data. Similar graphing was performed as was done during the original analysis.

While data were collected and collated for a U.S. Group 8, it was determined that this data set was recertification data and potentially a duplication of other provided data. With the exception of a single sample included in the overall analyses, the recertification data were removed from the analyses.

2.1.2 Analysis

For the following evaluations, individual charts were prepared to consider the following trends:

- Motor Octane Number (MON) vs. Lead
- MON and Supercharge Rating (SCR) vs Lead.
- Median Distillation Ranges
- MON vs. Lead vs. Calculated Aromatic Content

Provided data were analyzed to determine the average values (mean), the median values (centermost), the maximum value, the minimum value, and the standard deviation. The lead content was further analyzed to determine the percentage distribution of the samples on lead content. This statistical evaluation was used to prepare the observations related to the production of ASTM D910 100VLL fuels. 100VLL was added to the specification following the 2010 data review. 100VLL represented a 20% reduction in permissible maximum lead (0.45 g Pb/L) as compared to the traditional 100LL with a permissible maximum lead content of 0.56 g Pb/L.

In the original 2010 analyses, there was also a consideration for the contributions of aromatics on the lead content of the final fuel. Ultimately, no correlation was found in the 2010 data and no conclusions were drawn. None of the data provided for this work had aromatic contents reported, and a similar analysis related to reported aromatic content could not be performed on the current data. However, to help industry understanding, the aromatic concentration of the fuel samples was estimated using

ASTM D3338. ASTM D3338 is a correlation method compared to bomb calorimeter determination of AvGas energy content and, where used, reversing the calculation provides a reasonable calculation of the actual concentration of aromatics in the fuel.

Using the formula provided in D3338, the following Excel analysis was done with the provided data. This formula takes the distillation temperatures, the density, the energy content, and the sulfur content, and mathematically estimates the aromatic content based on provided aromatic equation constants. The net heat of combustion value, QP, is a correction of the net heat of combustion based on the QP equation constants and the measured energy content. All of the constants are provided by ASTM D3338. For calculations, sulfur values reported as a “less than” value were manually entered as “0.0”. For data which provided the density as API ° Gravity, the calculation density kg/m^3 = (141.5/(API+131.5))*1000 was used.

Table 5 - Calculation of Estimated Aromatic Content

			(Spreadsheet Cell)
T10% v/v	**°C**	66.1	E7
T50% v/v	**°C**	102.2	E8
T90% v/v	**°C**	109.9	E9
Density	**kg/m3**	716.1	E10
Energy Content	**MJ/kg**	43.85	E11
Sulfur	**% m/m**	0.0005	E12
Aromatics	**% v/v**	8.3	
= ((E10*(D18-D30+D28*D17))-D23-D25*D17)/(D26*D17-D24+D27*E10-D29*D17*E10)			(Excel formula)
			(Cell)
T = (T10+T50+T90%)/3	92.73333		D17
QP	43.85017		D18
QP Equation Constants	0.10166		D19
	0.01		D20
	1		D21
Aromatic Equation Constants	5528.73		D23
	92.6499		D24
	10.1601		D25
	0.314169		D26
	0.079171		D27
	0.009449		D28
	0.000292		D29
	35.9936		D30

3 *Analysis Summary*

The original study performed in 2010 was specifically undertaken to determine the impact of reducing the maximum amount of lead within current U.S. production, based on the existing fuel properties. Following that effort, it was determined a reduction of 15% to 20% over the specified maximum lead offered an opportunity for a Very Low Lead grade, 100VLL with a maximum lead content of 0.45 gPb/l. That original sample set included 96 individual samples.

This current analysis was specifically to determine if a change of lead content has been realized since that original study. The data provided was expanded to include data from the Rest of the World (RoW) production sources which were not included in the original 2010 study. While the original study considered the fuels samples source by regions within the U.S. to determine if there was a regionality to the potential, the current analysis is restricted global production.

4 *Analysis of Properties*

The analyses include the minimum, average (mean), and maximum for each quality parameter in the set. The properties included, the motor octane number (MON), supercharge rating (SCR), lead content in g Pb/L, vapor pressure and other measured parameters.

4.1 Results

Table 7 - Analysis of Global Leaded AvGas Properties

Property	Units	Minimum	Mean	Maximum	D910 Spec
MON	ON	100.0	102.4	105.0	Min 99.6
Supercharge	PN	130.0	134.2	141.0	Min 130
Lead	gPb/L	0.31	0.46	0.56	Min 0.28
Sulfur	% m/m	<0.00001	-	<0.01	Max 0.05
Vapor Pressure @ 38 °C	kPa	39.6	44.6	49.0	Min 38.0 / Max 49.0
Density	kg/m³	691.9	708.6	728.2	Report
IBP	°C	27.8	34.7	39.0	
T10%	°C	59.0	67.4	75.0	Max 75
T40%	°C	90.0	96.5	103.0	Min 75
T50%	°C	93.9	100.6	105.0	Max 105
T90%	°C	102.0	111.8	131.0	Max 135
FBP	°C	113.0	131.8	157.0	Max 170
T10% +T50%	°C	161.0	168.1	180.0	Min 135
Residue	% v/v	0.5	1.0	1.5	Max 1.5
Loss	% v/v	0.1	0.9	1.5	Max 1.5
Net Heat	MJ/kg	43.50	43.91	44.46	Min 43.5
Aromatics (D3338)	% vol	0.0	9.3	18.9	NA
Freeze	°C	<-80.0	-	<-58.0	Max -58
Copper Corrosion	Rating	1B	-	1A	Max 1
Oxidation Stability Potential Gum (5 or 16 hours)		<1	-	3	Max 6
Lead Precipitate		0	-	<1	Max 3
Water Reaction	mL	-1	-	1	Max ±2
Existent Gum	mg/100ml	<1	-	1	NA

4.2 Discussion

A brief discussion for each Avgas specification parameter is provided below. Graphs for each major property were generated and are included to help visualize the data distribution. The following additional analyses are also included for the global leaded Avgas data:

- MON versus Tetraethyl Lead content for grades 100LL / 100VLL.
- Percentage meeting 100LL (>0.45 – 0.56 gPb/l) versus 100VLL (0.28 – 0.45 gPb/l).
- Comparison versus 1960 United States Department of the Interior Bureau of Mines survey data for Grade 100/130.

4.2.1 Octane Quality

The mean MON was 102.1 ON. Product quality ranged from 100.0 to 105 ON with no batches recorded at the ASTM D910 / Defence Standard 91-090 100LL /100VLL specification minimum of 99.6 ON

4.2.2 Supercharge

The mean Supercharge for 100LL /100 VLL Avgas was 134.1 PN. The lowest result was 130.0 PN, at the specification minimum limit.

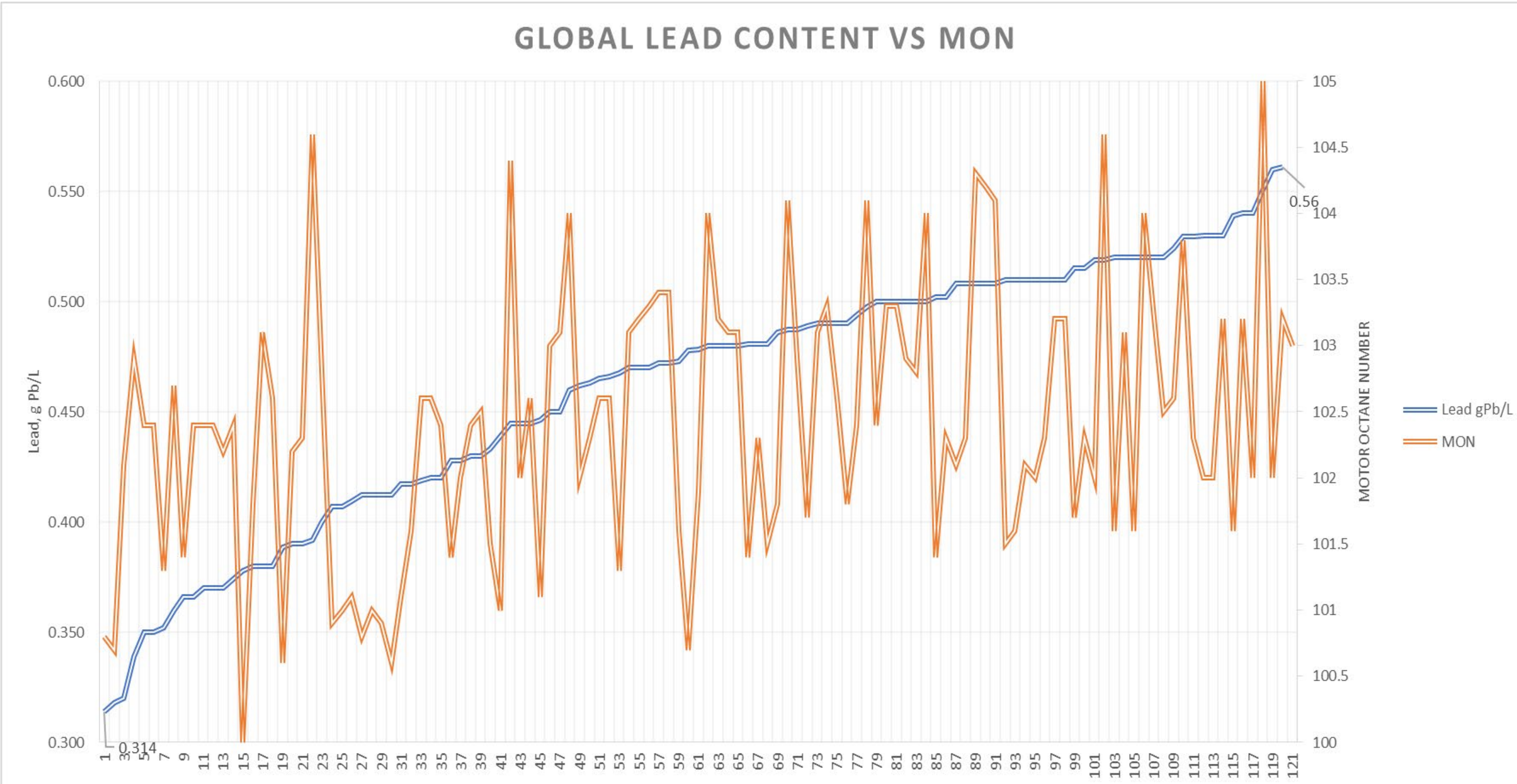


Figure 1 - 100LL/100VLL MON and Tetraethyl Lead

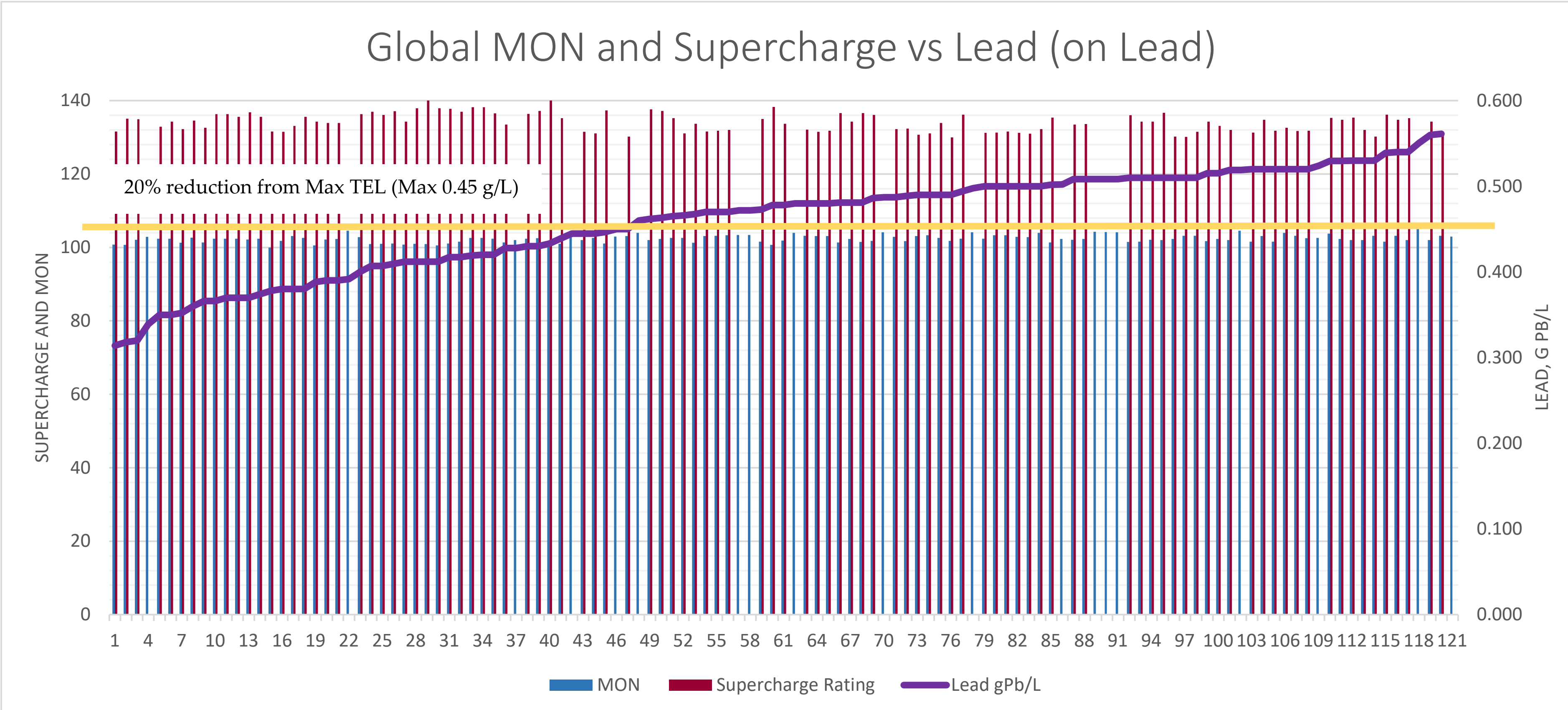


Figure 2 - 100LL/100VLL Supercharge and MON versus Tetraethyl Lead

4.2.3 Lead

The minimum / mean / maximum tetraethyl lead content for 100LL /100VLL was 0.31 / 0.48 / 0.56 gPb/l respectively. A review of the CoAs showed that 37.5% met the ASTM D910 Avgas 100VLL criteria of 0.45 gPb/L maximum. Trace Tetraethyl Lead in UL91 Avgas ranged from <0.0026 to 0.008 gPb/l (not shown) highlighting the importance of including the permissible 0.013 gPb/l specification limit in a mixed leaded / unleaded Avgas transition market.

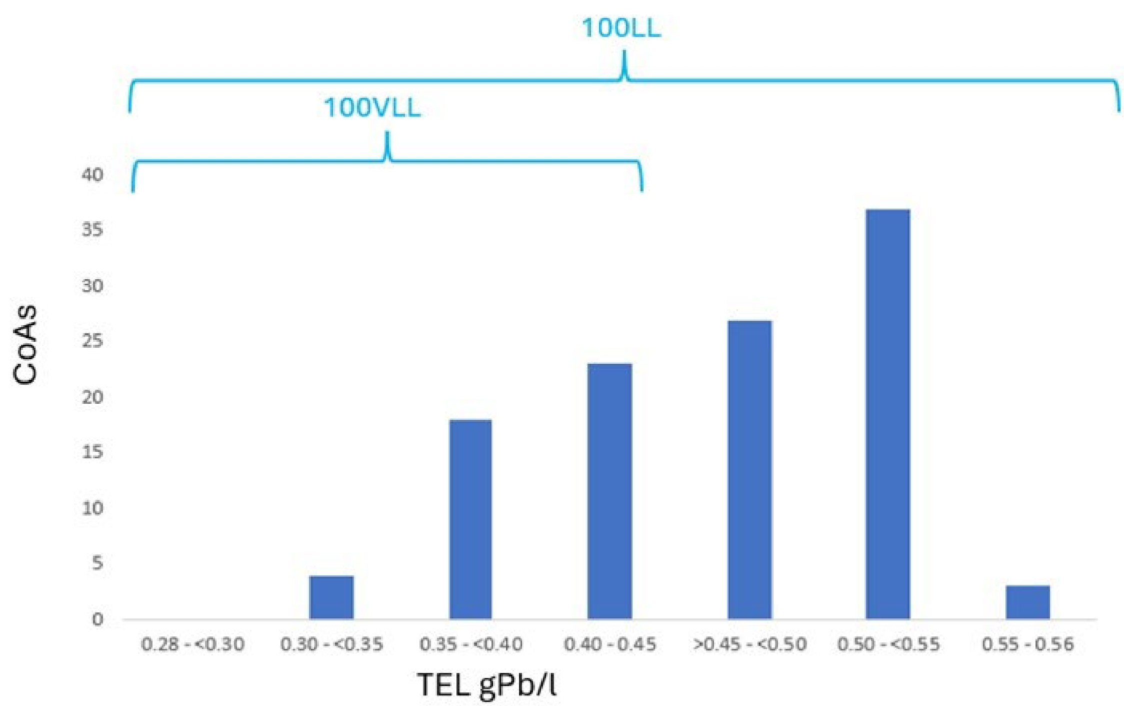


Figure 3 - 100LL/100VLL Tetraethyl Lead Content

4.2.4 Sulfur Content

The sulfur content of all AvGas grades was found to be low, <0.01% m/m often being cited for results below the test method detection limit.

4.2.5 Density

The mean density for 100LL / 100VLL was 708.6 kg/m^3 with a minimum of 691.9 kg/m^3 and a maximum of 728.2 kg/m^3. The distribution is given in Figure 4, the orange bar being just the current data; the blue bar also includes the original FAA data.

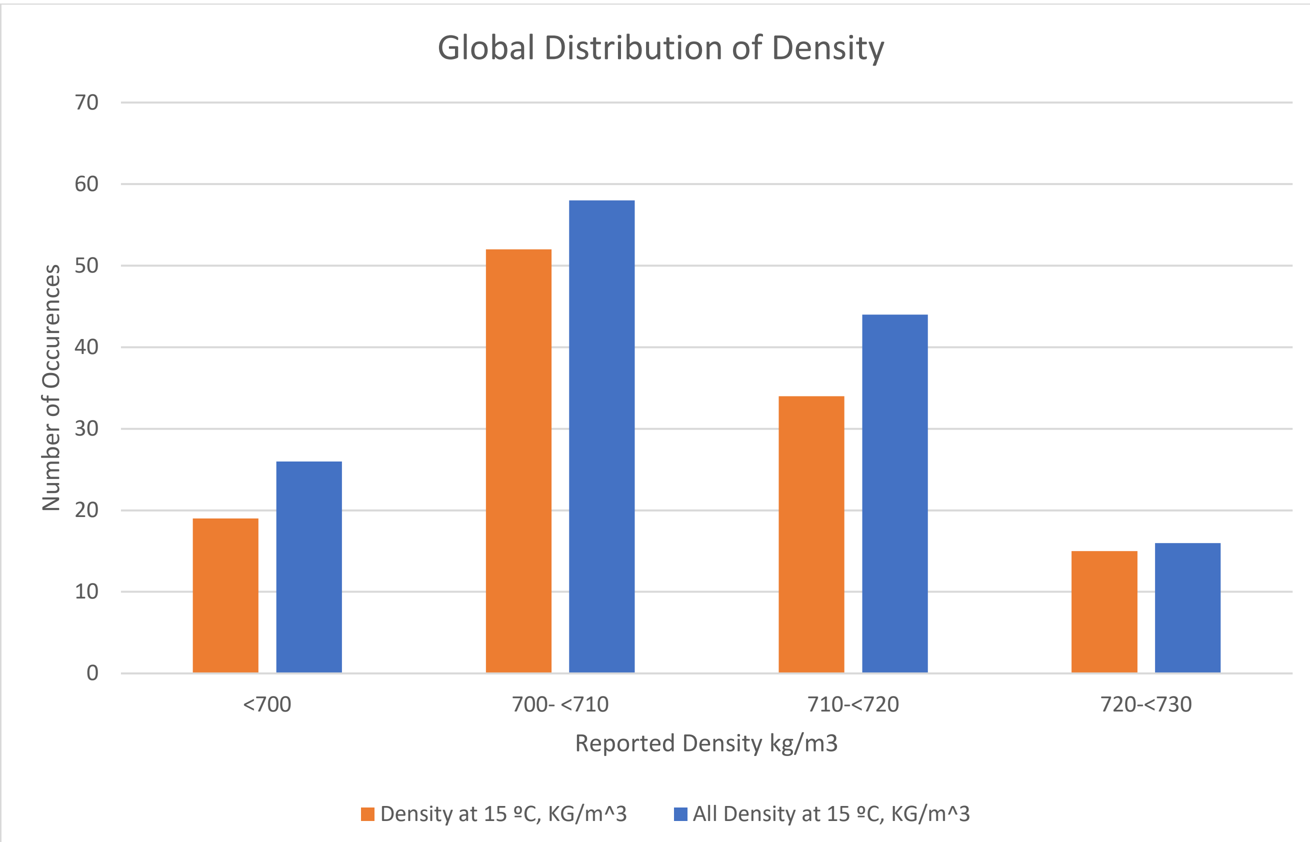


Figure 4 - Range of Reported Density

4.2.6 Vapor Pressure

The mean vapor pressure was 44.7 kPa. The maximum vapor pressure was 48.95 kPa. The lowest vapor pressure of the survey was 39.6 kPa, which is 1.6 kPa above the minimum limit of 38.0 kPa. The distribution is given in Figure 5, the orange bar being just the current data; the blue bar also includes the original FAA data.

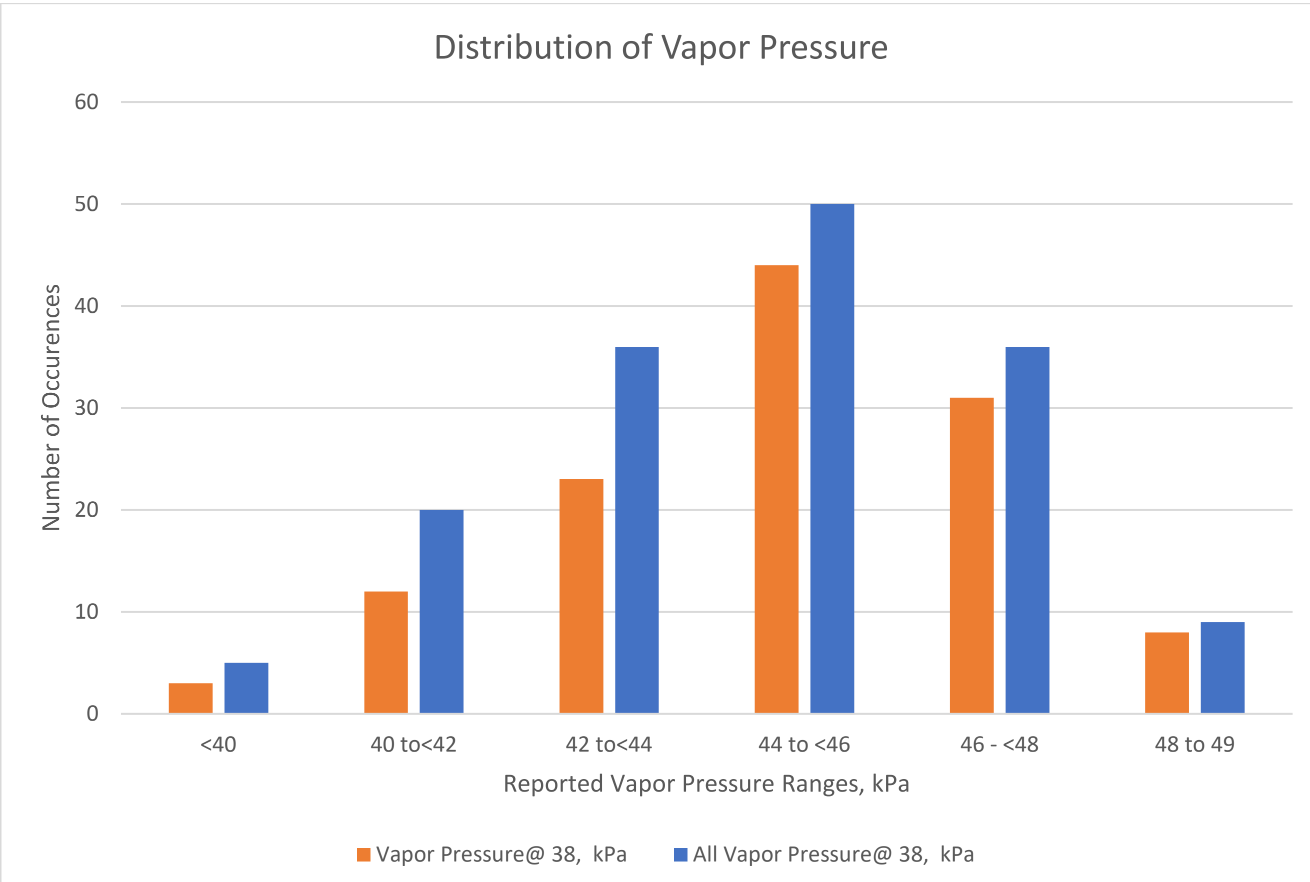


Figure 5 – Range of Reported Vapor Pressure

4.2.7 Distillation

The mean distillation parameters for global leaded AvGas production are provided in Table 6. Data were found very similar for all regions. The lowest initial boiling point was recorded at 27.8 °C and the highest final boiling point 157.0 °C. T10% and T50% were constraints for some production with 12 CoAs within <1° of the specification limits of 75 and 105 °C. In the charts below, the orange bar is just the current data; the blue includes the original FAA data.

Table 6 - Analysis of Average Current Global Leaded AvGas Distillation Properties

Parameter	Units	Mean	Min	Max	D910 Spec
IBP	°C	34.7	27.8	39	Report
T10%	°C	67.1	58.7	75.0	Max 75
T40%	°C	96.1	69.9	103.0	Min 75
T50%	°C	100.6	93.9	105.0	Max 105
T90%	°C	112.0	102.0	131.0	Max 135
FBP	°C	132.1	113.0	157.0	Max 170
T10% +T50%	°C	174.6	159.6	195.6	Min 135
Residue	% v/v	1.0	0.5	1.5	Max 1.5
Loss	% v/v	0.9	0.1	1.5	Max 1.5

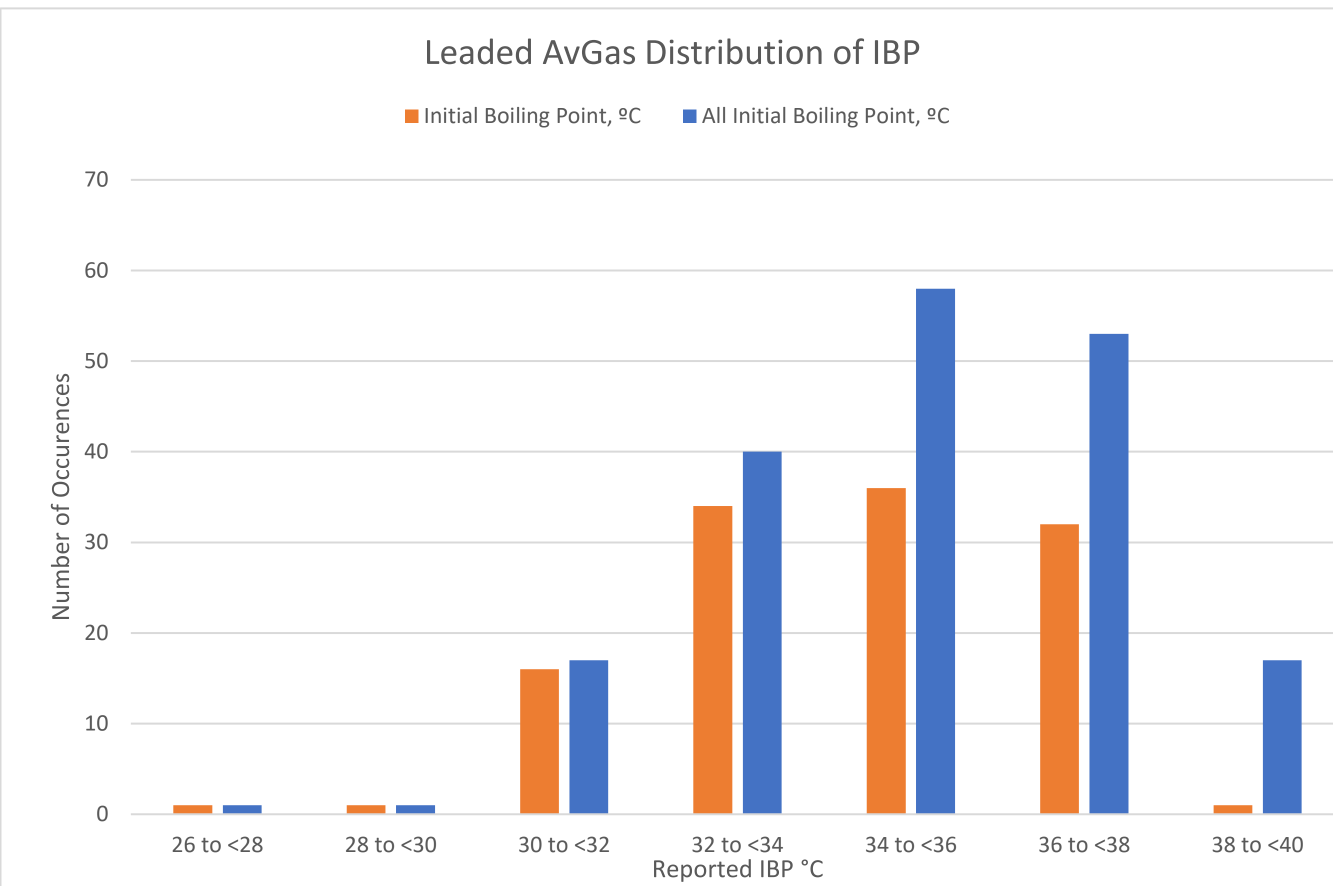


Figure 5 - Leaded AvGas Distribution of Initial Boiling Point

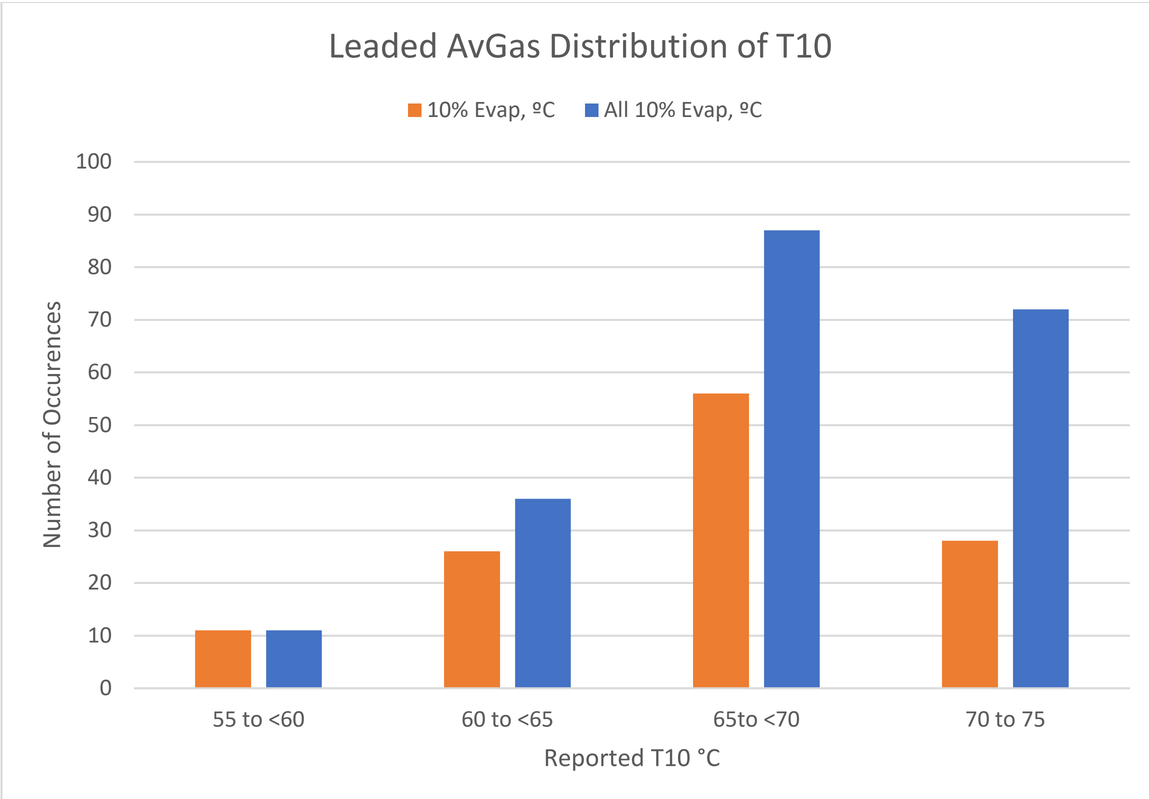


Figure 6 - Leaded AvGas Distribution of T10%

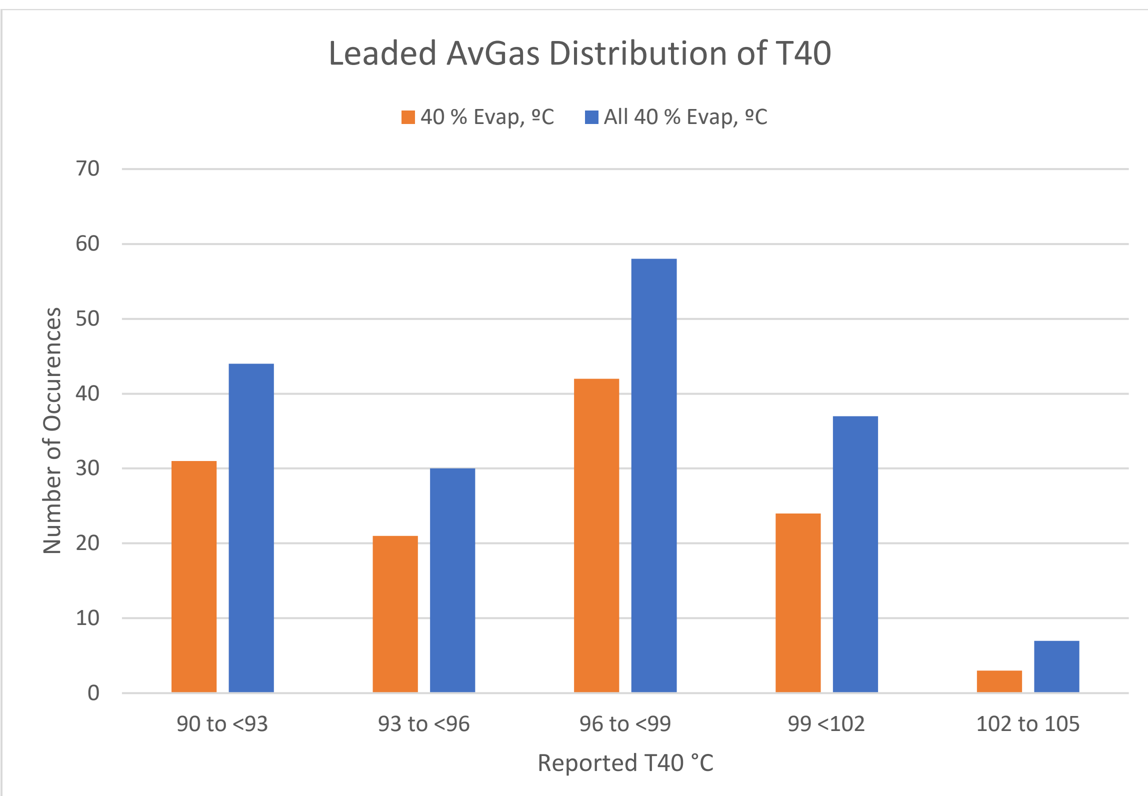


Figure 7 - Leaded AvGas Distribution of T40%

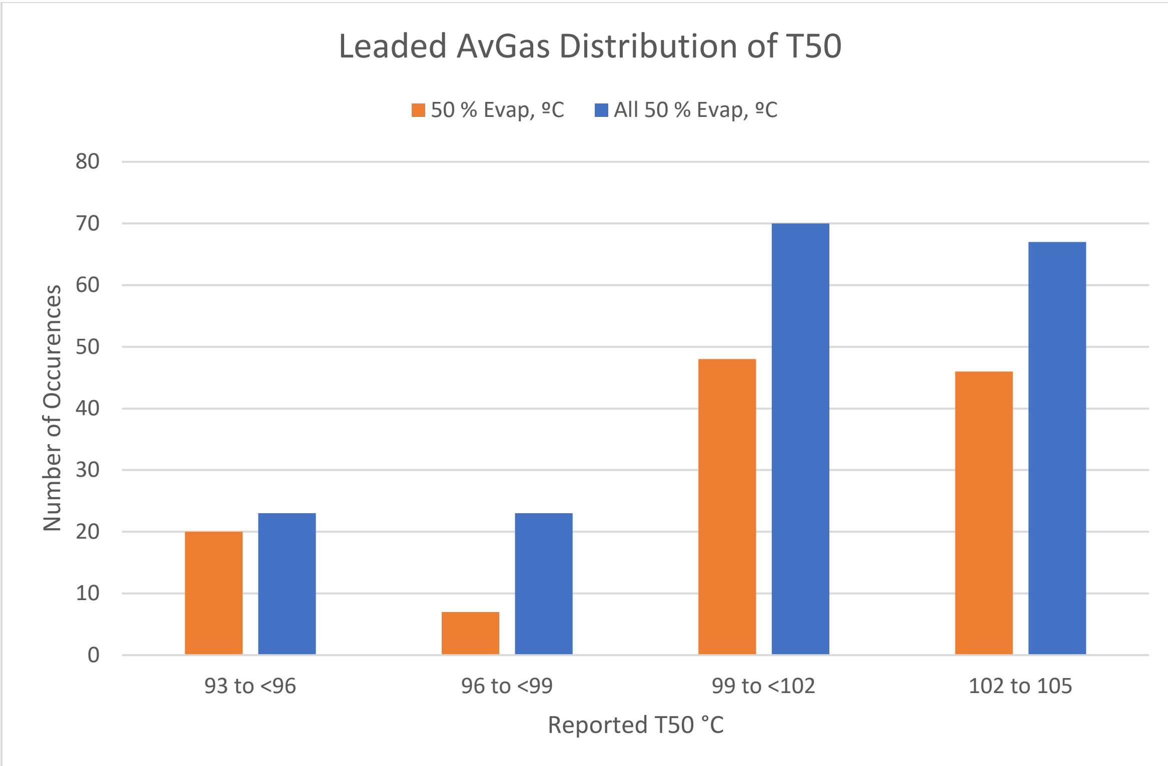


Figure 8 - Leaded AvGas Distribution T50%

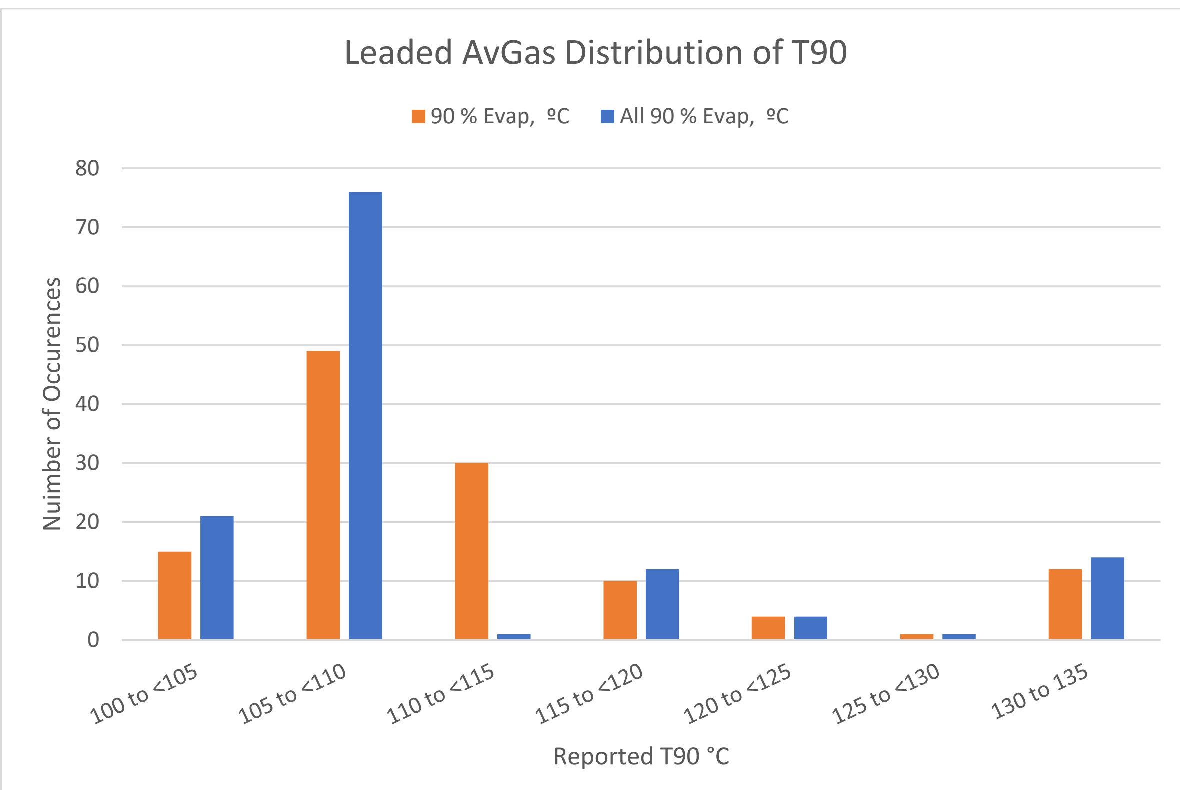


Figure 9 - Leaded AvGas Distribution T90%

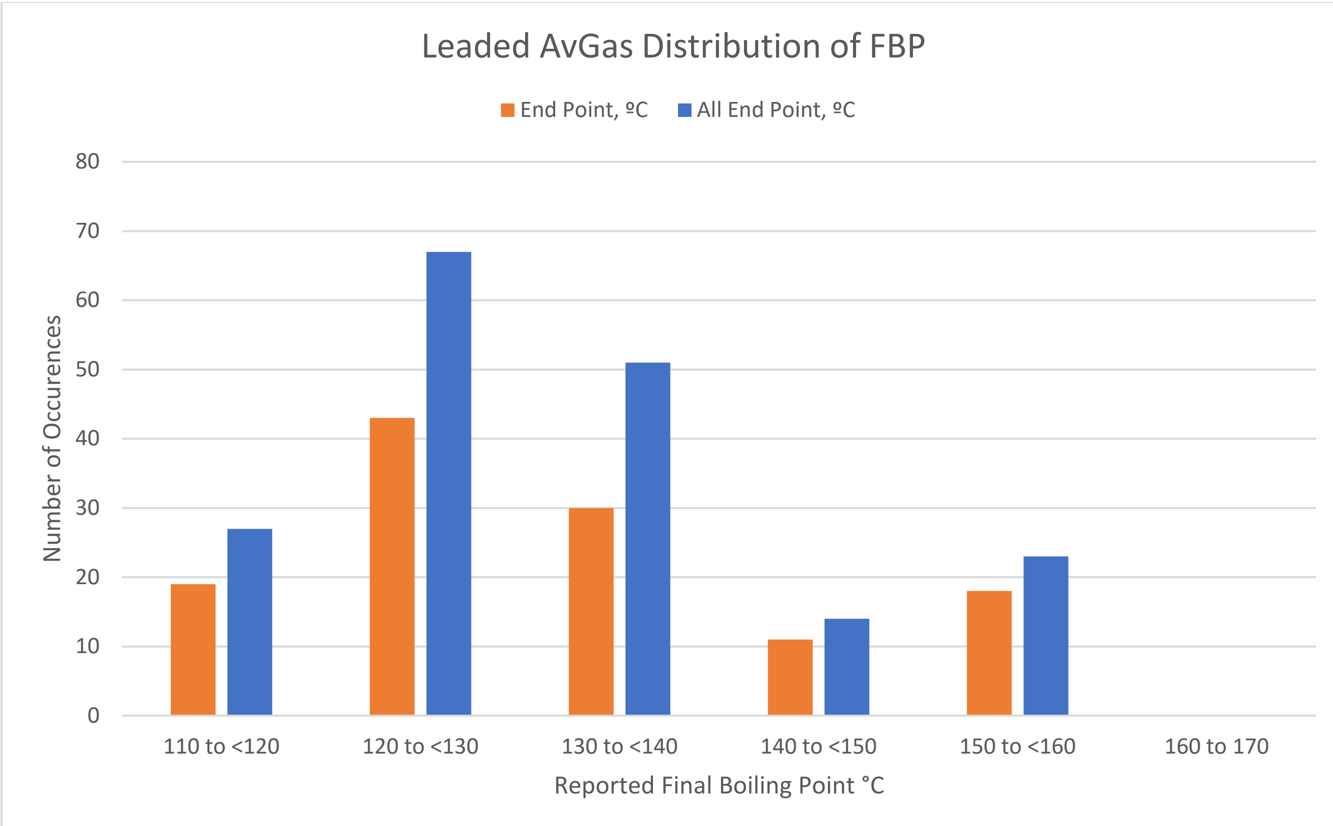


Figure 10 - Leaded AvGas Distribution of Final Boiling Point

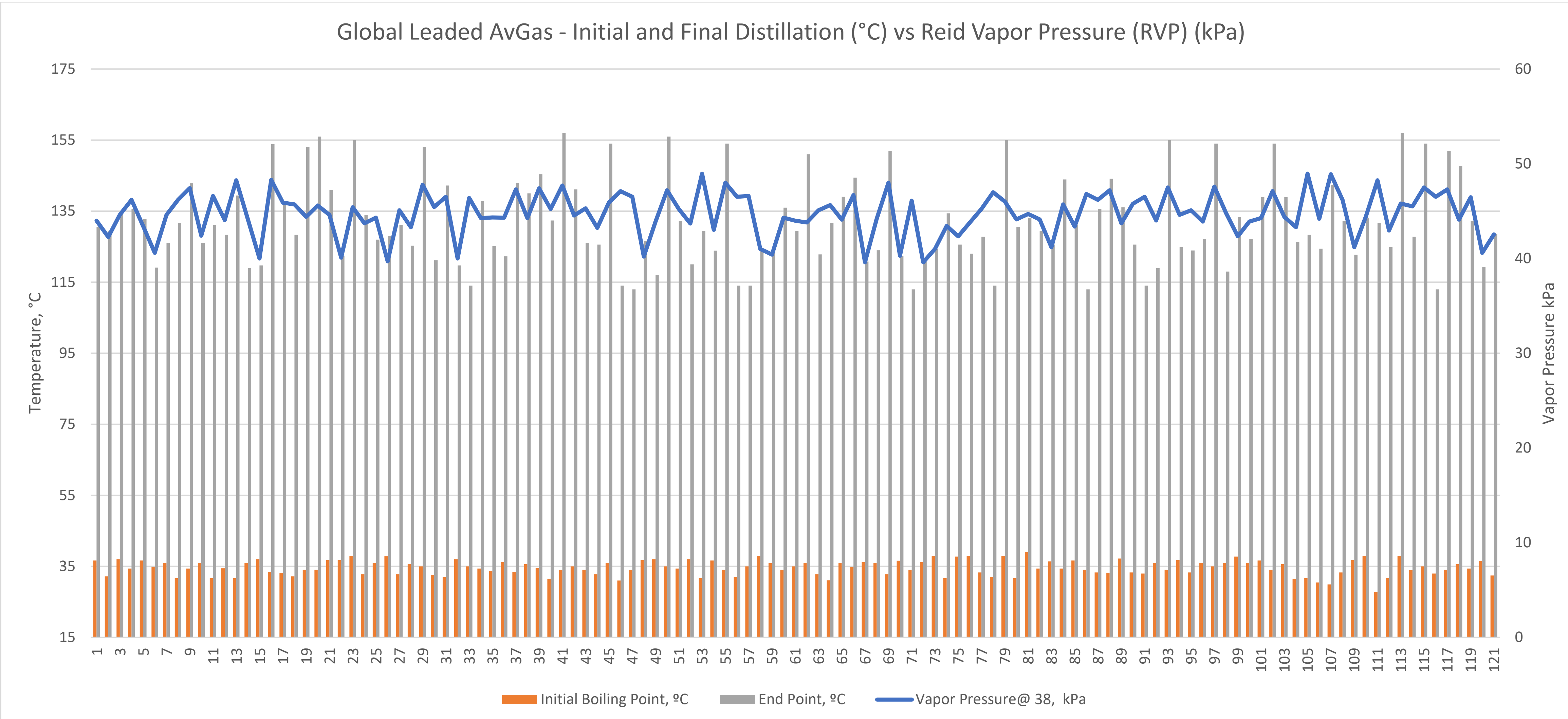


Figure 11 - Global Leaded AvGas Initial and Final Boiling Point (IBP & FBP) versus Reid Vapor Pressure (RVP)

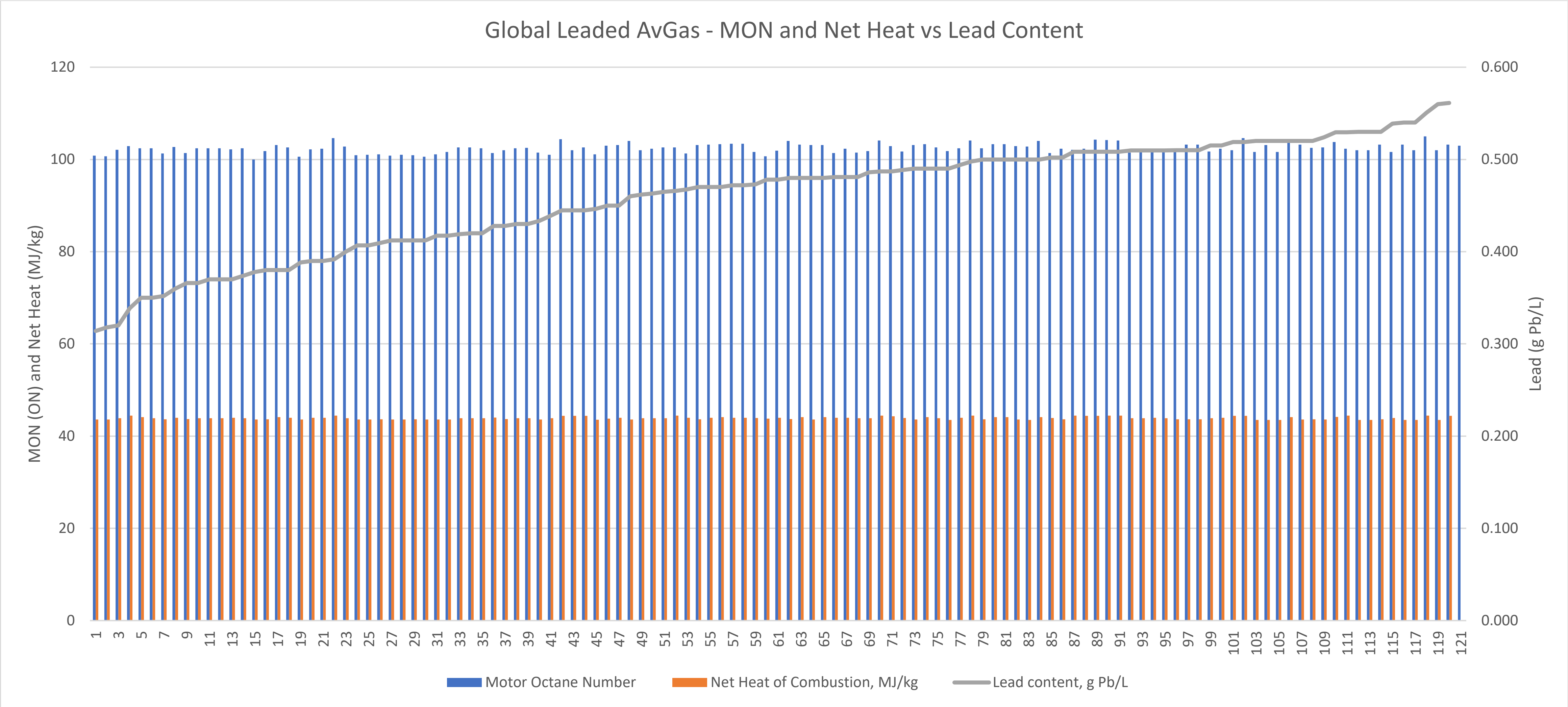


Figure 12 - Global Leaded AvGas - Motor Octane and Net Heat of Combustion vs Lead Content

4.2.8 Energy Content

100LL/100VLL energy content ranged from the specification minimum, 43.5 MJ/kg, to 44.5 MJ/kg with a mean of 43.9 MJ/kg.

4.2.9 Aromatic Content

Aromatic content for the data set was calculated using ASTM D3338 as detailed in section 2.1.1. Results are summarized in Figure 13 and Table 7 - Analysis of AvGas Aromatic Concentration (D3338).

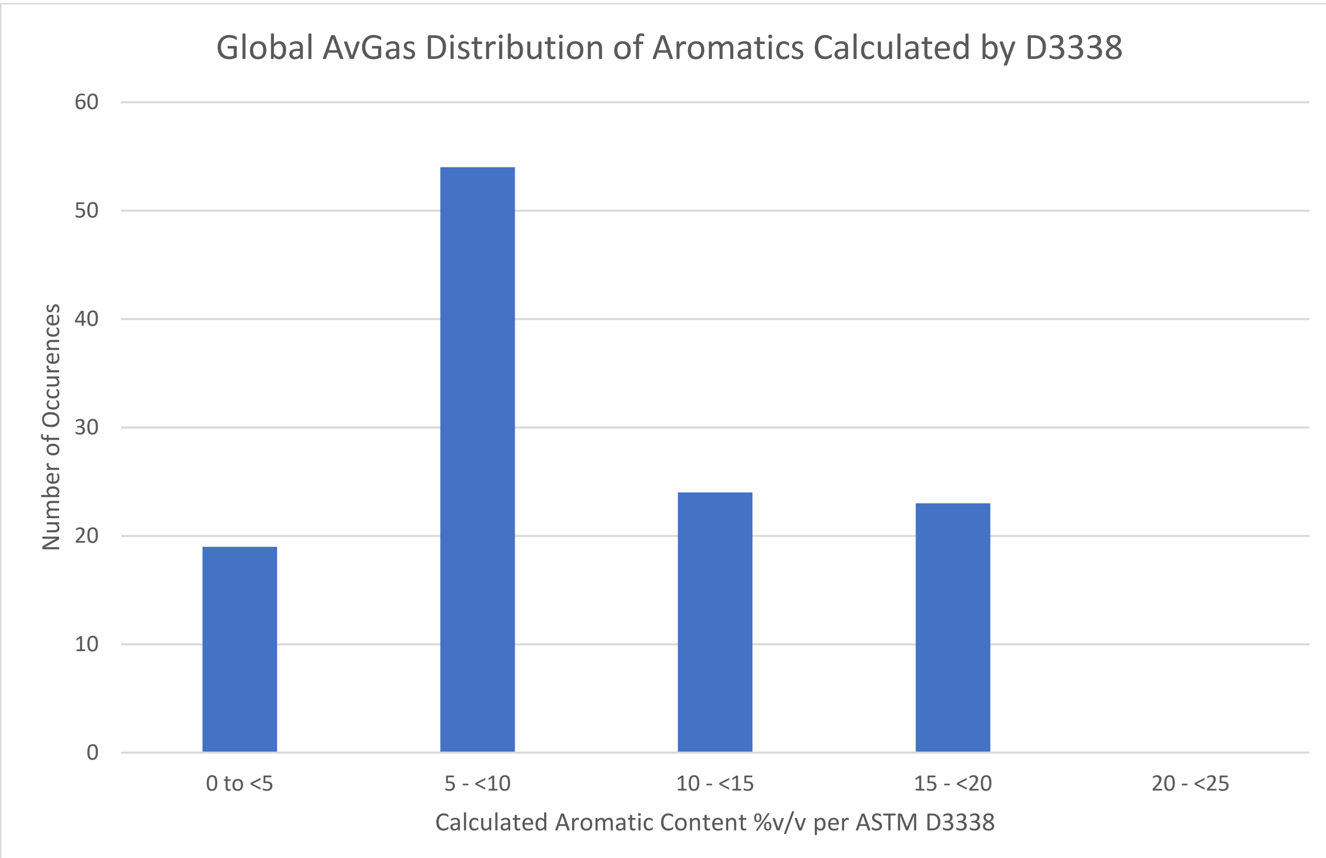


Figure 13 - Global AvGas Aromatic Content (D3338 Calculated)

Table 7 - Analysis of AvGas Aromatic Concentration (D3338)

Aromatics	Min % v/v	Mean % v/v	Max % v/v
U.S. 100LL / 100VLL	0.0	6.5	12.8
RoW 100LL / 100VLL	5.8	12.4	18.9

The lowest concentration of aromatics was 0.0% v/v. The maximum calculated concentration was 18.9% v/v. This is significantly below the theoretical specification maximum, ASTM D910 of 25%, section X1.8.1.

4.2.10 Freeze Point

All freeze point results were below the -58 °C specification maximum with many reporting the result below the limit of instrument detection. The highest and lowest recorded values were -60.6 and -72.0 °C respectively.

4.2.11 Copper Corrosion

All Copper Corrosion results met the required maximum rating of 1 with reports of 1, 1A and 1B.

4.2.12 Oxidation Stability

The data featured 5-hour and 16-hour oxidation stability tests, probably a reflection of ASTM versus Defence Standard product requirements. In both cases potential gum was low, a maximum of 3 mg/100 ml being recorded. Results were typically <1 mg/100 ml and no reported lead precipitate.

4.2.13 Water Reaction

Water reaction results were low for all data with many reported as <1 ml. The highest result was 1.0 ml. Water reaction analysis was primarily to detect any ethanol from the motor gasoline pool entering AvGas production. Results suggest good segregation of products.

4.2.14 Existent Gum

Existent gum is reported as part of Defence Standard 91-090 specification requirements. Data indicated low levels with a maximum of 1 mg/100 ml.

4.2.15 MON versus Lead Content

A review of the MON vs lead content shows the not unexpected relationship of an increasing lead content with increasing MON value as the use of lead as an additive is driven by the octane and supercharge requirements of the specification. However, this is also related to the use of aromatics and the natural characteristics of the aviation alkylate used. Thus, a plot of MON vs lead content does show a weak correlation showing that in general less lead additive may correspond to a lower MON.

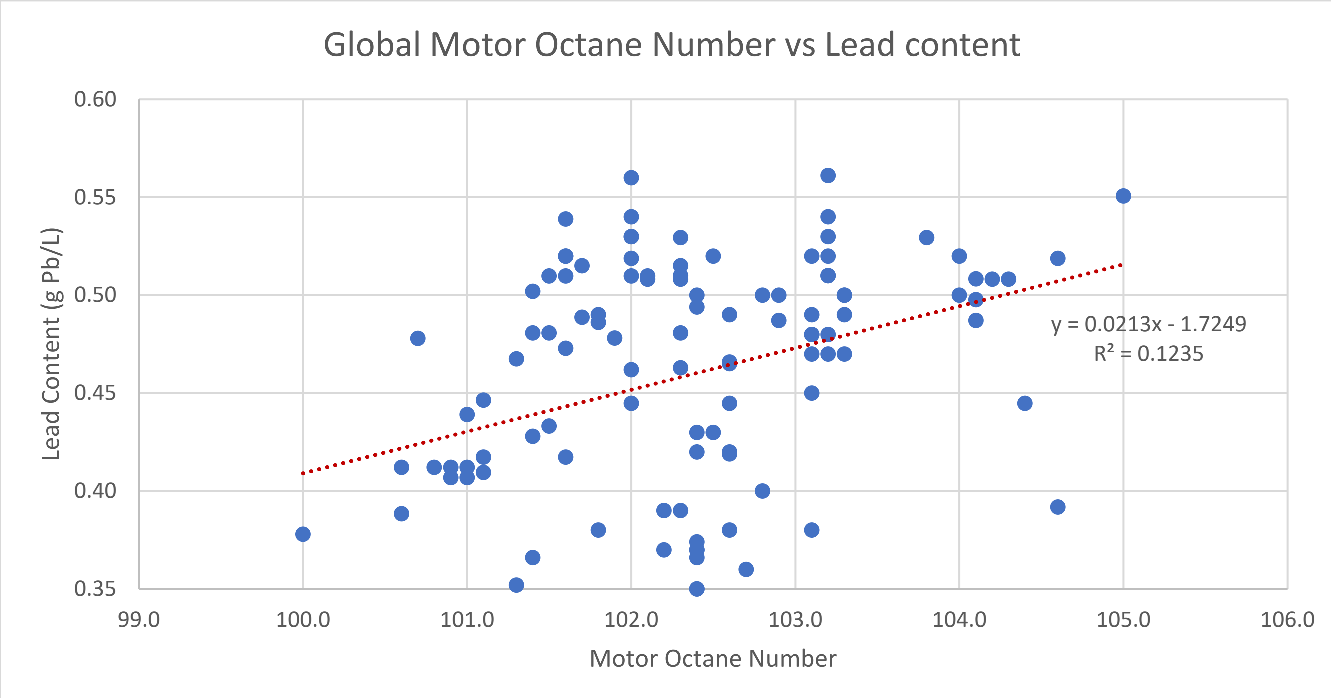


Figure 14 - Motor Octane Number vs Lead Content in All Leaded Fuels

4.2.16 100VLL

Based on the leaded Avgas data, 40% of the global Avgas pool would satisfy the lower maximum lead limit of 100VLL (0.28 to 0.45 g Pb/l). Considering the MON-TEL data in Figure 14, this suggests potential challenges for Avgas supply should the industry attempt to fully transition to 100VLL. The grade also exhibits a slightly lower mean MON with the minimum value of 100.0 approaching the 99.6 D910 lower limit, Table 8.

Table 8 - 100LL and 100VLL MON Analysis

Grade Allocation	MON Min	MON Mean	MON Max
100LL (>0.45 – 0.56 gPb/l)	100.7	102.6	105.0
100VLL (0.28 – 0.45 gPb/l)	100.0	101.9	104.6

4.2.17 Comparison Versus 1960 Avgas Quality

A limited comparison of the combined leaded AvGas 100LL/100VLL quality data from the current survey with United States Department of the Interior Bureau of Mines data for 1960 Grade 100/130 was performed, Appendices, Section 7.2. This is summarized in Table 9. The reduction in TEL from 1.12 to 0.56 gPb/l maximum moving from Grade 100/130 to 100LL appears to have resulted in an increase in aromatics usage to recover octane, the mean result moving from 5.7 to 9.3% v/v. However, overall, leaded Avgas has remained a very consistent product considering the almost 60 years difference in survey data.

Table 9 - Current Survey Global 100LL / 100VLL comparison to 1960 Bureau of Mines Data

Property	Units	1960 Survey Mean	Current Survey Mean
MON	ON	103.3	102.4
Supercharge	PN	131	134.2
Lead	gPb/L	1.0	0.46
Vapor Pressure @ 38 °C	kPa	46.2	44.6
Density	kg/m^3	703.6	708.6
IBP	°C	42.8	34.7
T10%	°C	65.0	67.4
T40%	°C	92.2	96.5
T50%	°C	97.8	100.6
T90%	°C	118.3	111.8
FBP	°C	155.0	131.8
Residue	% v/v	0.9	1.0
Loss	% v/v	1.0	0.9
Net Heat	MJ/kg	44.1	43.9
Aromatics (D3338)	% v/v	5.7	9.3
Freeze	°C	<-60	<-58
Copper Corrosion	Rating	1	1
Ox Stab (5 or 16hr)			
Potential Gum	mg/100ml	0.7	-
Lead Ppt	mg/100ml	0.1	-
Water Reaction	mL	0.1	-

5 *AvGas Quality Over Time*

In an attempt to consider the other properties reported on the CoA, and comment on changes over time, all of the data from both the original FAA study and the contemporary study were compiled into a single spreadsheet. These data were then sorted by provided sample date. Due to the full blinding performed on the current CoA data, the date information was lost. However, the current data were data from the last 10 years and is provided as a general continuation of the original data. In cases where no date was provided, a notional date was entered solely for the purpose of sorting. Note that a set of FAA Study data were excluded due to questionable data source and a significantly skewed distillation profile. These were data provided from an engine program and not original certificate of analysis data.

Following the sort, graphs including trendlines for each major property were generated and are included in the Appendix section.

With the exception of motor octane number and net heat of combustion, there does not appear to be any trending changes in properties over the global pool of data over time.

6 Conclusions

Based on the review of the provided data in this study, the conclusions drawn are:

1. Of the U.S. samples, reviewed before blinding 45% met the current 0.45 g Pb/L limit for compliance with 100VLL or a 20% reduction over current 100LL maximum levels (0.56 g Pb/L).
2. Of the RoW 100 octane samples, reviewed before blinding, 37% met the current 0.45 g Pb/L limit for compliance with 100VLL or a 20% reduction over current 100LL maximum levels (0.56 g Pb/L).
3. Based on the trends within the datasets, margin on MON appears to be reducing versus past analysis. There were 24 samples with a MON less than 102 and five samples with MON of less than 101, a margin of 1.4 ON versus specification minimum of 99.6 ON. While in the 2010 data, there was a single value of 100.0 reported, the maximum MON reported was 108, significantly higher than reported for the current analysis U.S. and RoW maxima 105.0 and 103.3 respectively. The mean MON value reported in the 2010 was 103.6; the mean in the current U.S. dataset was 102.3 (102.1 including the 100VLL). All samples had a MON of at least 100.0, but this potential reduction was noteworthy.
    a. In the 2010 analysis, over 95% of the data had motor octanes values higher than 102, and 85% were over 103. A review of the U.S. data for this report determined that only 54% were higher than 102 and only 20% were over 103. 88% of the U.S. samples were above 101, meaning 12% were between 100 and 101.
    b. A review of the combined data plotted against lead content only gave a weak correlation highlighting the importance of the hydrocarbon AvGas base-stock to final quality.
4. Volatility results were in agreement with specifications except for the 2010 data set where two unusually low results were reported for T40% and T10% + T50%, possibly typographical errors. T10% and T50% maximum appeared to be production constraints with occasionally product at the limit of the specifications 75 and 105 °C respectively.

5. For all data, except MON and Net Heat of Combustion, there does not appear to be any trends in properties which would likely exceed variability in the population or the test method.

6. When compared to United States Department of the Interior Bureau of Mines data for 1960 Grade 100/130, the aromatic concentration in current 100LL / VLL appears to have increased from 5.7 to 9.3% v/v on average. Aside from this, product quality has remained surprisingly consistent for more than 60 years.

The remaining reviews are a result of plotting trending data for the remaining measured properties by date for the original 2010 FAA dataset and the current data. Because there was no RoW data in the 2010 study, all of the RoW data are from the current study. Data are displayed in Section 7.

7 Appendices

7.1 Trending Analysis Over Time

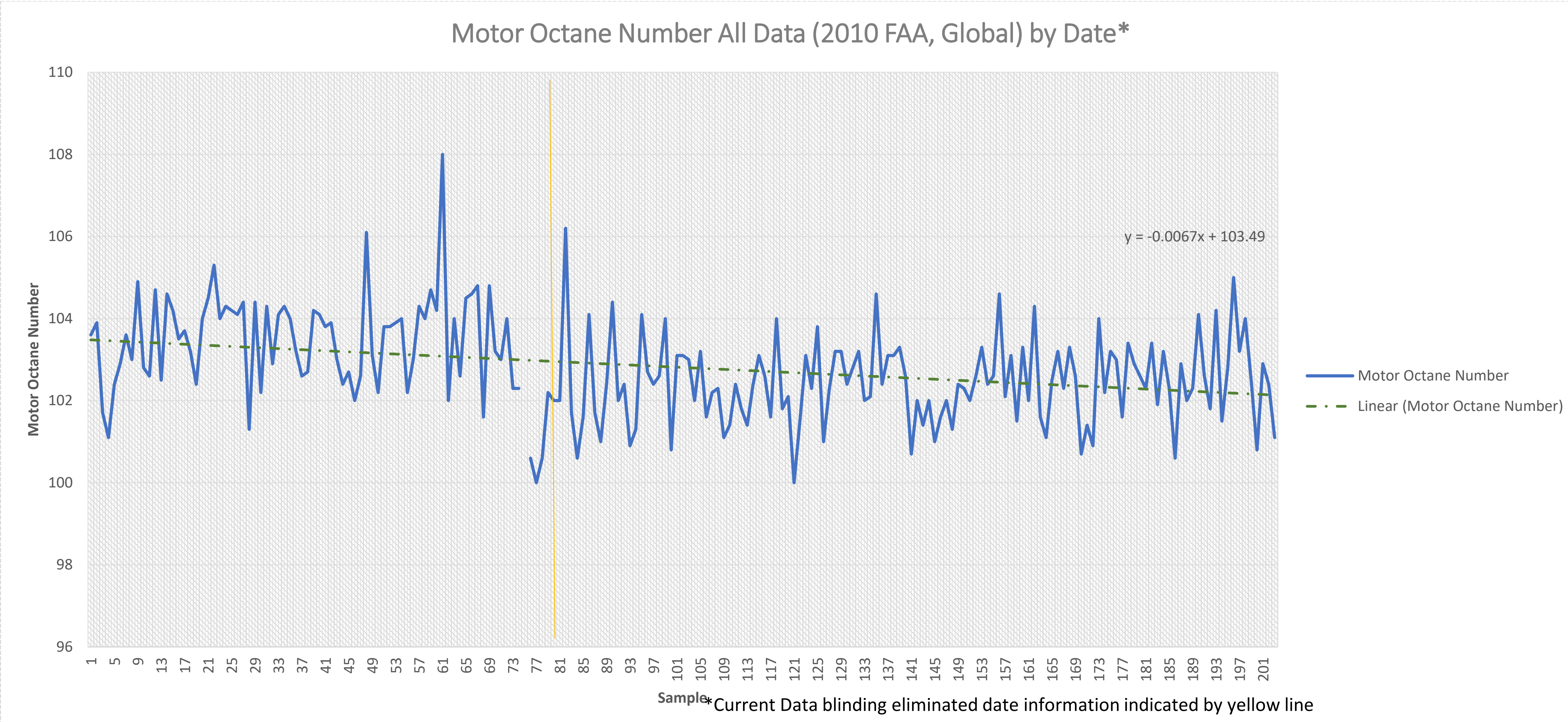


Figure 15 - All Leaded Data including FAA, current Global AvGas; MON by Date*

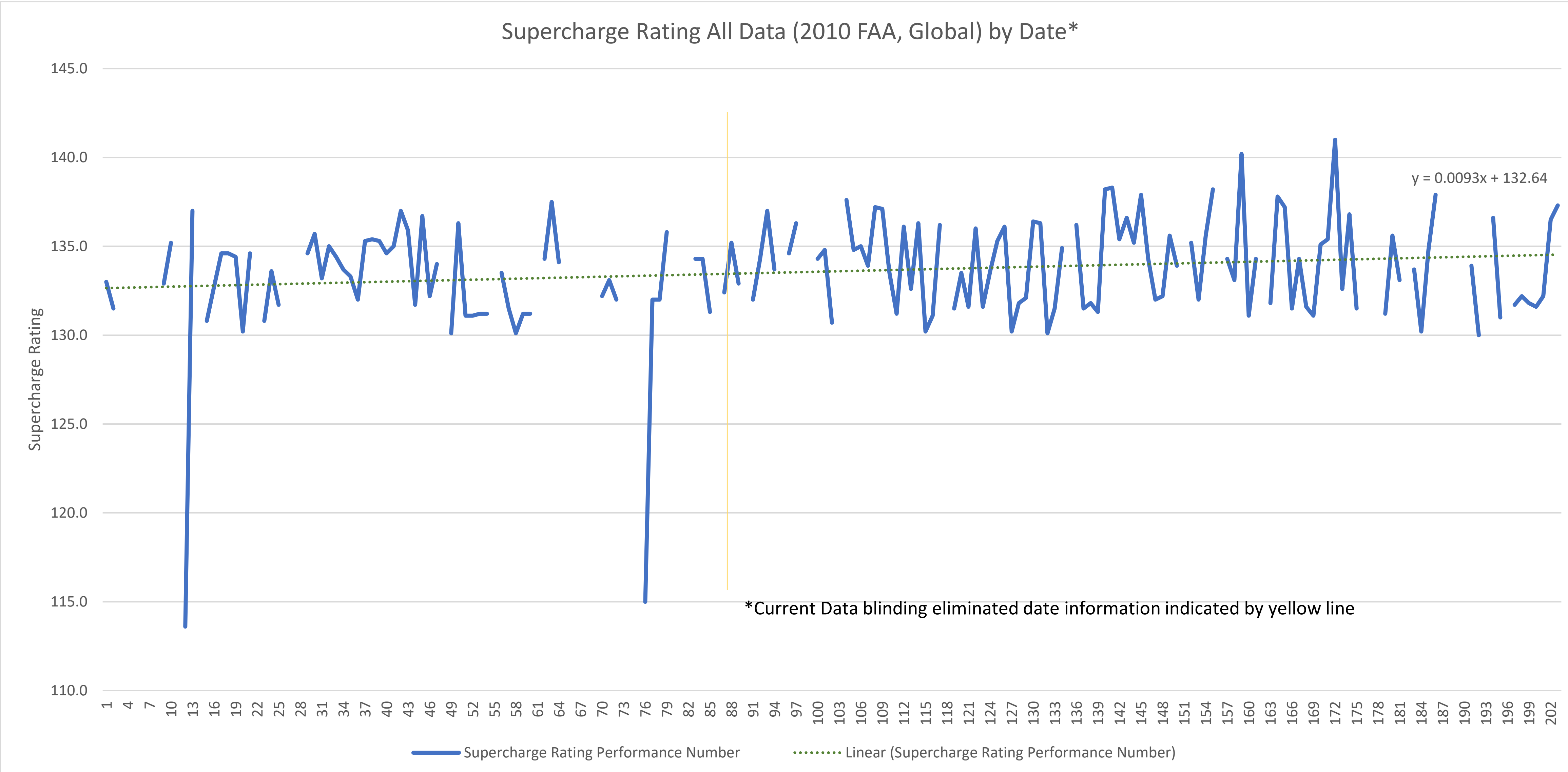


Figure 16 - Supercharge Rating Performance Number, All Data including FAA, current Global AvGas; by Date*

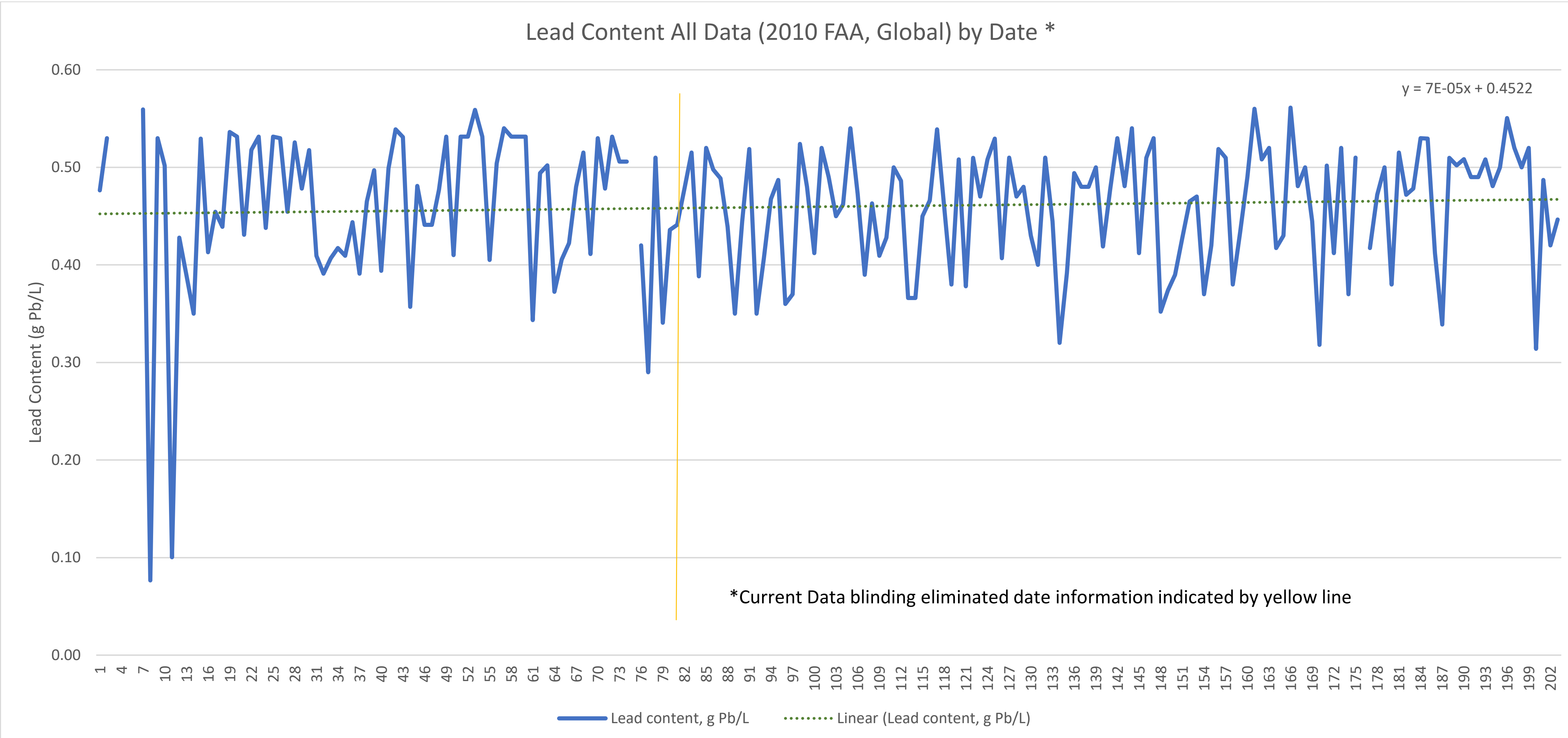


Figure 17 - Lead Content, All Data, including FAA, Global AvGas; by Date*

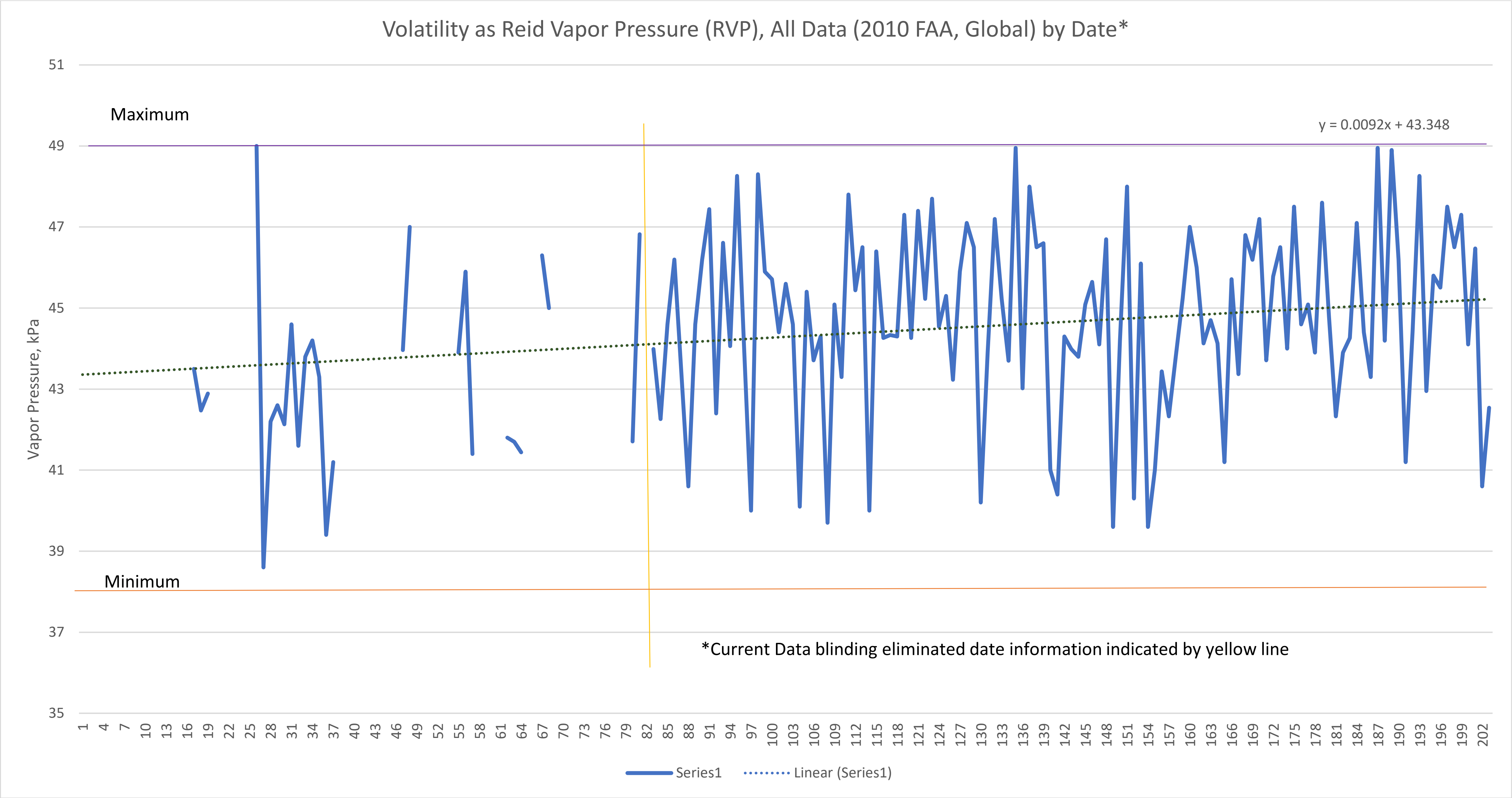


Figure 18 - Volatility as Reid Vapor Pressure (RVP), All Data, including FAA, Global AvGas; by Date*

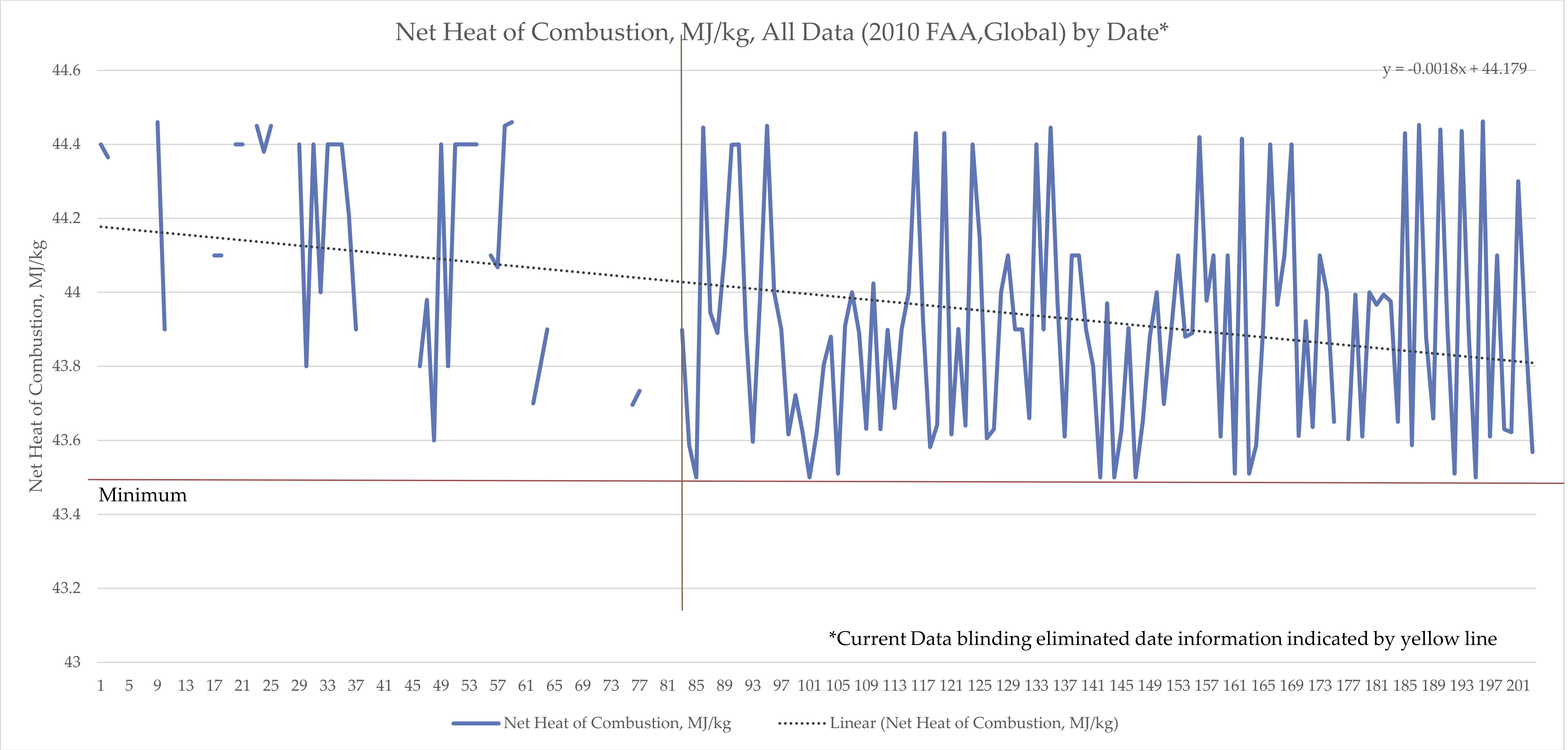


Figure 19 - Net Heat of Combustion, All Data, including FAA, Global AvGas, by Date*

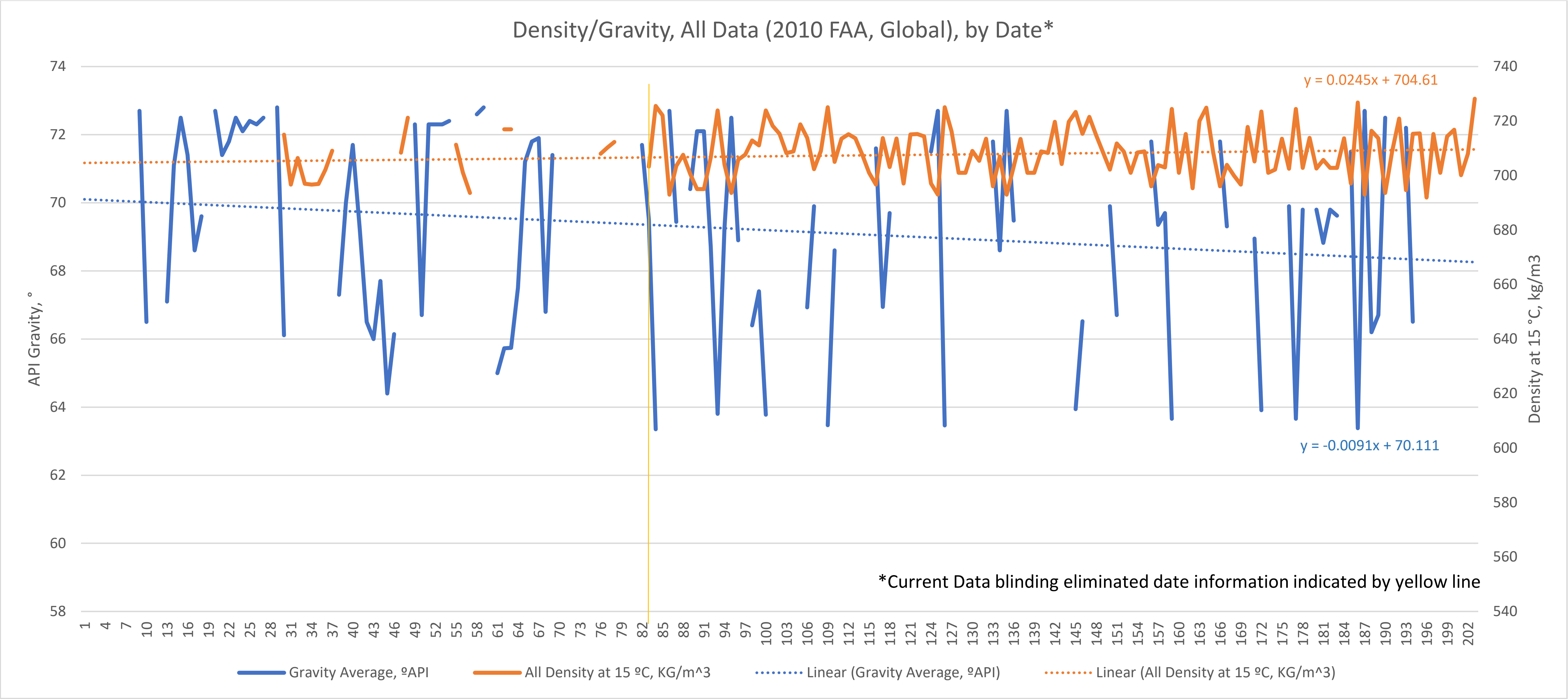
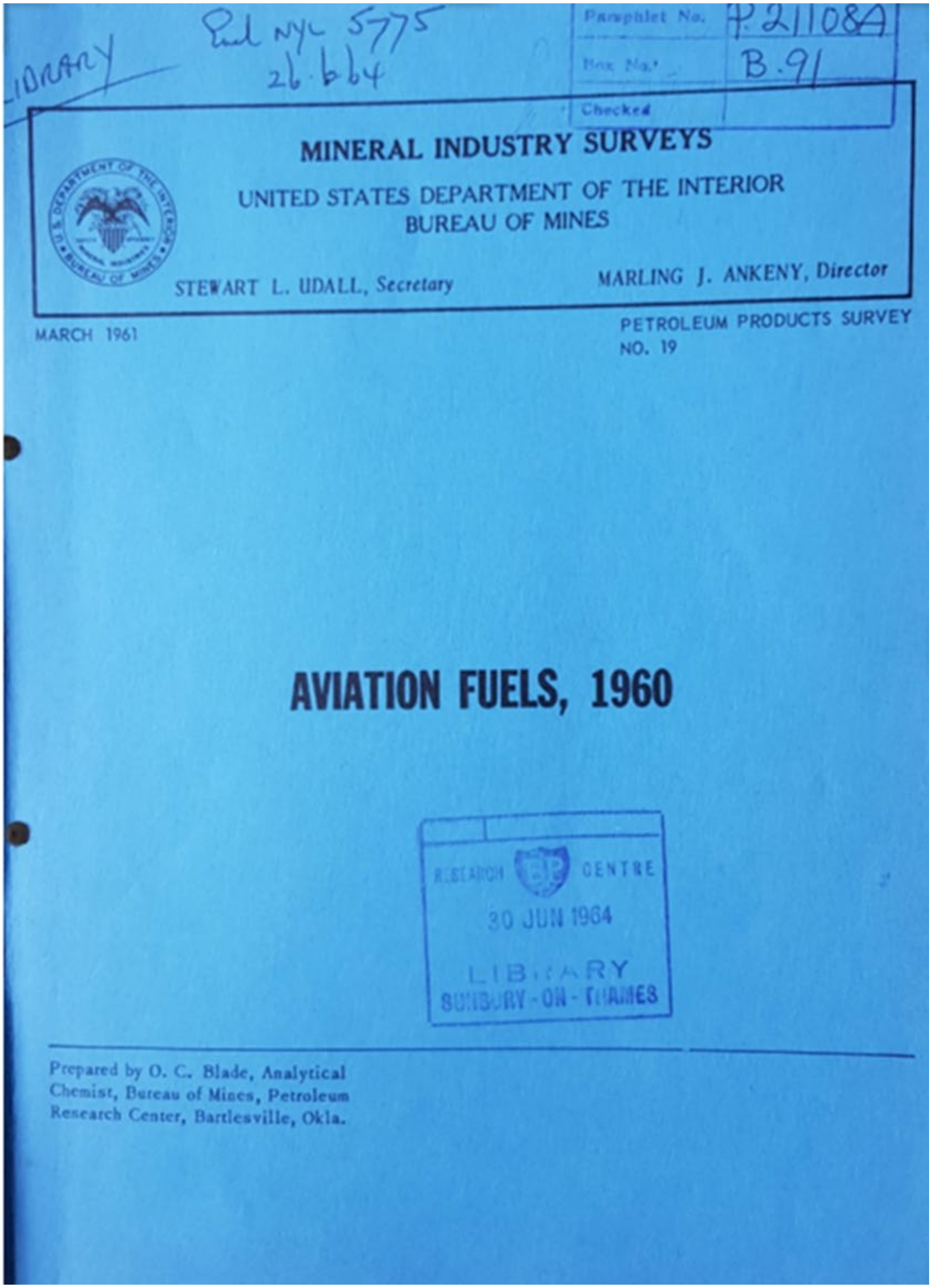


Figure 20 - API Density and Gravity, All Data, including FAA, Global; by Date*

7.2 National Bureau of Mines 1960 Avgas Survey Data



MINERAL INDUSTRY SURVEYS

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

STEWART L. UDALL, *Secretary* MARLING J. ANKENY, *Director*

MARCH 1961

PETROLEUM PRODUCTS SURVEY
NO. 19

AVIATION FUELS, 1960

Prepared by O. C. Blade, Analytical
Chemist, Bureau of Mines, Petroleum
Research Center, Bartlesville, Okla.

TABLE 9. - Grade 100/130 aviation gasoline: Inspection data furnished by participating companies for their products, 1960

Item	Knock value: TEL in isooctane ml./gal.: Aviation, ASTM D614	Knock value: TEL in isooctane ml./gal.: Supercharged, ASTM D909	Knock value: Performance number: Aviation	Knock value: Performance number: Supercharged	Tetraethyllead, ml./gal. ASTM D526 1/	Distillation, ASTM Method D86: Temperature (corrected to sea level) °F.: Percent evaporated: IBP	5	10	15	20	30	40	50	70	90	95	EP	Sum 10+50	Percent: Res.	Percent: Loss	Slope of distillation curve at 10 percent	Reid vapor pressure, ASTM D323, lb.	Copper-dish gum, ASTM D910, mg./100 ml.	Potential gum, 16 hr., ASTM D873, mg./100 ml.	Visible lead precipitate, ASTM D873, mg./100 ml.	Water tolerance ASTM D1094, ml. 2/	Net heat of combustion, Btu per lb., ASTM D1405 3/	Aniline point, ASTM D611, °F.	Gravity, ASTM D287, ° API	Aniline-gravity constant	Freezing point, ASTM D1477, °F.	Sulfur (uncorrected for TEL), ASTM D1266, weight percent 4/	Kinematic viscosity, ASTM D445, at 70° F., centistokes
Commercial aviation gasolines																															
41	0.10	1.38	104	131	3.50	104	123	143	155	167	192	208	220	239	269	290	308	363	1.0	1.0	3.2	6.8	-	0.6	<0.5	0.0	18,754	126.0	64.6	8,140	<-76	0.01	-
42	.25	1.36	109	131	3.88	106	132	152	164	174	188	200	209	228	254	284	330	360	.9	1.1	3.2	7.0	0.7	.4	.0	.0	19,030	159.5	70.7	11,277	<-80	.02	0.59
43	.17	1.31	106	130	4.39	113	141	157	164	169	179	188	197	209	232	253	291	354	.8	1.2	2.3	6.7	-	.8	.0	.0	18,778	127	66.1	8,395	<-76	.01	-
44	.30	1.31	111	131	3.00	112	130	148	160	172	180	204	213	220	242	267	309	361	1.0	1.0	2.9	6.9	-	1	1	(1)	19,044	159.5	71.6	11,420	<-76	.01	-
45	.16	1.36	106	131	3.91	108	138	150	158	166	184	200	209	222	250	279	328	359	1.0	1.0	2.0	6.4	1	1	.0	.0	18,998	156	69.9	10,904	<-80	.010	.73
46	.27	1.35	110	131	3.91	106	134	150	159	167	183	198	207	221	240	254	308	357	1.0	1.0	2.5	6.7	-	.7	.0	.0	18,998	155.3	70.3	10,918	<-76	.02	-
47	.30	1.31	111	130	2.96	100	135	146	158	167	188	201	215	228	249	272	308	361	1.0	1.0	2.3	6.7	2.0	1.0	.2	1.0	18,920	145.9	68.7	10,023	<-76	.011	.691
48	.49	1.33	116	131	3.98	103	128	148	163	176	194	205	213	225	245	267	337	361	1.0	1.5	3.5	6.9	-	.2	.0	(1)	19,033	159.1	70.9	11,280	<-100	.000	-
49	.32	1.51	111	133	3.92	107	132	146	161	168	185	199	209	221	232	239	279	355	.9	1.0	2.9	6.5	-	.4	.1	.5	19,036	158.2	71.6	11,327	-85	.009	-
50	.40	1.29	113	130	2.61	114	139	153	165	175	192	205	215	231	253	272	318	368	1.0	1.0	2.6	6.0	1	1	.0	.0	19,001	157.5	69.5	10,946	<-76	.02	.58
51	.36	1.32	112	131	2.75	104	133	146	155	163	184	197	209	220	242	267	312	355	.7	.8	2.2	6.8	-	.8	.0	.0	4/ 19,018	163.7	73.0	11,950	-80	.009	.56
52	.32	1.43	111	132	3.76	110	140	147	167	177	196	206	214	226	246	267	308	361	.8	1.2	2.7	6.9	1	1	.0	.0	18,916	146.5	68.1	9,977	<-76	.011	-
53	.31	1.30	111	130	3.96	105	135	146	153	159	174	188	199	224	249	269	321	345	1.0	1.0	1.8	6.7	1.0	1.0	.0	.0	19,022	155.8	71.7	11,171	<-76	.01	.60
54	.40	1.30	113	130	3.9	102	133	152	165	175	194	207	215	226	242	260	310	367	1.0	1.1	3.2	6.8	1	1	.0	.0	18,966	153	68.9	10,542	<-80	.01	.60
55	.33	1.42	111	132	3.87	98	125	142	154	164	184	203	213	223	241	263	306	355	1.0	1.0	2.9	6.6	.0	.0	.0	.5	18,987	153.7	70.1	10,774	<-76	.009	.65
56 6/	.30	1.30	111	130	3.83	117	148	158	172	182	196	208	212	226	248	274	324	370	1.0	1.0	2.4	6.6	1	1	1	.0	18,848	137.5	66.9	9,199	<-76	.008	.63
57 6/	.33	1.46	111	132	3.94	116	139	153	165	178	197	210	220	233	256	283	328	373	1.0	1.0	2.6	7.0	.0	.0	.0	.0	18,959	151.9	68.8	10,451	<-76	.003	-
58 6/	.22	1.36	108	131	2.83	109	132	151	160	173	189	202	213	225	240	255	314	364	.7	.3	2.8	6.7	1.0	.7	.1	.0	19,044	159.0	72.0	11,448	<-76	.023	-
59 6/	.17	1.32	106	130	2.87	106	135	148	156	165	180	196	206	220	234	251	300	354	1.0	1.0	2.1	6.8	.4	.6	.0	(1)	18,942	148	69.3	10,256	<-76	.001	.583
60 6/	.18	1.50	107	133	2.86	106	132	146	155	162	178	194	206	225	247	267	330	352	1.0	1.0	2.3	6.6	2.0	.2	.0	(1)	18,902	143.0	68.7	9,824	<-76	.015	-
61 6/	.02	1.30	101	130	2.98	115	135	144	149	153	162	172	184	207	235	263	303	328	.8	.5	1.4	6.7	.3	.5	.1	(1)	19,101	165.4	73.0	12,074	<-76	.013	-
62 6/	.16	1.28	106	130	3.92	120	142	151	160	168	184	200	215	232	255	270	309	366	1.0	1.0	1.8	6.5	1.0	1.0	.0	.0	18,859	138.7	67.2	9,321	<-76	.01	.61
63 6/	.14	1.29	105	130	3.84	110	135	142	148	151	163	177	193	224	251	267	301	335	1	1	1.3	6.5	2	.0	.0	.0	18,730	120.7	65.2	7,870	<-76	.01	.58
64 6/	.36	1.36	112	131	3.91	116	139	148	155	159	171	185	195	215	233	249	275	343	1.0	1.0	1.6	6.4	1	1	.0	<1	19,009	155.3	71.0	11,026	<-76	.013	-
65 6/	.28	1.28	110	130	3.91	113	141	150	156	162	174	185	195	214	246	271	314	345	1.0	.5	1.5	6.6	1	1	.0	.0	19,004	154	71.3	10,980	<-76	.013	.61
Average 25 samples	.27	1.35	110	131	3.57	109	135	149	159	168	184	198	208	223	245	266	311	357	.9	1.0	2.4	6.7	1.0	.7	.1	.1	18,956	150.0	69.6	10,440	<-76	.011	.616
Military aviation gasolines																															
66	0.25	1.35	109	131	3.93	104	134	148	157	165	180	193	205	219	237	257	306	353	1.0	1.0	2.3	6.6	1	1	0.0	0.0	19,020	155.5	71.7	11,149	<-76	0.01	0.59
67	.07	1.29	103	130	4.40	102	121	141	152	162	180	199	213	232	260	286	304	354	1.0	1.0	3.1	6.7	-	<.5	<.5	.0	18,770	127.5	65.2	8,313	<-76	.01	-
68	.30	1.21	111	129	4.42	114	140	158	170	179	194	204	214	223	243	262	290	372	1.0	1.0	3.0	6.7	-	1	.0	(1)	18,968	153.0	69.0	10,557	<-76	.01	-
69	.20	1.30	107	130	4.56	107	133	143	149	154	164	174	182	198	225	240	273	325	1.0	1.0	1.6	6.9	2.3	2.0	.0	.0	18,992	151	71.7	10,827	<-76	.010	.63
70	.43	1.77	114	136	4.47	110	123	146	163	175	191	204	214	225	243	272	330	360	1.0	1.3	4.0	6.7	-	2.4	.0	.0	19,028	159.0	70.7	11,241	<-76	.01	.70
Average 7/ 15 samples	.23	1.36	108	131	3.78	111	135	148	158	166	180	194	204	221	244	264	307	352	1.0	.9	2.0	6.7	1.1	.8	.1	.0	18,945	148.0	69.4	10,271	<-76	.011	.617

TABLE 10. - Grade 108/135 aviation gasolines: Inspection data furnished by participating companies for their products, 1960

Item	Aviation, ASTM D614	Supercharged, ASTM D909	Aviation	Supercharged	Tetraethyllead, ml./gal. ASTM D526	IBP	5	10	15	20	30	40	50	70	90	95	EP	Sum 10+50	Res.	Loss	Slope of distillation curve at 10 percent	Reid vapor pressure	Copper-dish gum	Potential gum	Visible lead precipitate	Water tolerance	Net heat of combustion	Aniline point	Gravity	Aniline-gravity constant	Freezing point	Sulfur	Kinematic viscosity
Commercial aviation gasolines																															
71	0.40	1.70	113	135	3.00	112	132	152	166	178	196	209	215	219	236	254	282	367	1.0	1.0	3.4	7.0	-	2	0.0	(1)	19,058	162.0	71.6	11,599	<-76	0.02	-
72	.36	1.70	112	135	2.97	103	145	157	168	177	195	209	216	229	248	275	314	373	1.0	1.0	2.3	6.0	1.8	1.0	.3	1.0	18,930	148.3	68.3	10,129	<-76	.012	0.695
73	.28	1.71	110	135	2.64	106	133	147	157	165	184	201	212	225	251	260	316	359	1.0	1.0	2.4	6.7	-	.6	.0	.1	5/ 18,950	144.3	68.9	9,942	-76	.008	.53
74 6/	.43	1.77	114	136	2.87	116	138	150	157	164	174	192	204	217	230	260	279	354	1.0	1.0	1.9	6.3	1	1	.0	<1	18,960	151.3	69.2	10,470	<-76	.010	-
75 6/	.24	1.86	108	137	2.94	108	130	140	146	150	164	176	192	216	232	243	280	332	1.0	1.0	1.6	6.9	.6	.6	.0	(1)	18,938	146	69.9	10,205	<-76	.002	.559
Average 5 samples	.34	1.75	112	136	2.88	109	136	149	159	167	183	197	208	221	239	258	294	357	1.0	1.0	2.3	6.6	1.1	1.0	.1	.6	18,967	150.4	69.6	10,468	<-76	.010	.595

Military aviation gasolines
(see items 74 and 75)

7.3 Data

Data is available from CRC as a separate file