The quality of aviation fuel available in the United Kingdom

Annual survey 2014

CRC project no. AV-18-17

THE QUALITY OF AVIATION FUEL AVAILABLE IN THE UNITED KINGDOM ANNUAL SURVEY 2014

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ABSTRACT

This report, jointly funded by the Coordinating Research Council (CRC) and the Energy Institute (EI), contains a summary of the data relating to the specification properties for AVTUR (Jet A-1) supplied in the United Kingdom during 2014. The data are expressed in the form of histograms and mean values, which are graphically compared over the period 1986–2014. This report is the 37th in a series of survey reports.

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1 INTRODUCTION

Surveys relating to the specification properties of aviation turbine fuels supplied in the UK from 1974 onwards have been published annually by The Fuels and Lubricants Centre (FLC)[1] [1]–[24]. This report covers a similar survey for fuel (Jet A-1) supplied during the year 2014 involving 1 488 batches complying with Defence Standard 91–91[26]. Historically, this survey was funded by the UK Ministry of Defence (MoD) in support of their specification development activities. In recent years the Energy Institute (EI) has part-funded the work. However, after the 2008 survey was produced, the MoD ceased to fund the activity. Since then the EI and the CRC have jointly funded the survey in full.

The information contained in this report has been supplied by oil companies and associated test houses for main batches of aviation fuel released during 2014. The data are expressed in the form of histograms and mean values, which are graphically compared over the period 1986 to 2014. Arithmetic mean values are not used due to the variation in volume of each fuel batch from which data points are gathered. Instead, the mean values are weighted according to the relative fuel volume associated with each data point.

Historically most batches of jet fuel used for this survey were refined in the UK. However, over time many UK refineries have closed and more finished fuels have been imported into the UK. Although the data provided do not give exact details on the number of imports, it is expected that a large proportion of the data in this report is from imported batches. Therefore, the data presented are likely to be at least partly representative of jet fuel available worldwide.

The percentage of the results near to the specification limits are reported for selected properties. These properties were chosen for historical reasons (for comparisons with previous data) and include some properties which appear to limit jet fuel production. For the purposes of this report 'near specification limit' results are those that lie within the reproducibility of the method at the specification limit.

The report also contains a short discussion on each property and how the results are changing. Results that are close to, or outside, specification limits are noted. Other points of interest such as the distribution of results are commented on. Changes and trends may be of interest and importance to specification writers, OEMs, users, and refiners and may be significant even though they do not approach current specification limits. It is expected that this report will be of most use for specification development and associated test method development.

1 The Fuels and Lubricants Centre (FLC) was originally part of the UK Ministry of Defence (MoD), which then became an Agency of the MoD under the names DRA and DERA. FLC then became part of QinetiQ and has been part of Intertek since 2011.

2 RESULTS

The data reported have been abstracted from test certificates, or from electronic data supplied by oil companies, for new batches of AVTUR, either produced in, or imported into, the UK during 2014. The data for all but four of the specification properties for AVTUR are summarised in tables and figures in the Annexes. The data for copper corrosion and thermal stability were not included as the majority of results were identical. Copper corrosion results were typically 1A with a number of 1B results and thermal stability results were typically a <1 tube rating with no pressure drop. All thermal stability results were reported at 260 °C. Data for electrical conductivity were not included because at the point of testing, the conductivity of many batches was below the specified limits. This is permitted on the condition that Static Dissipater Additive (SDA) is added further downstream [26] to ensure that the conductivity limits are met at the point of delivery into aircraft.

2.1 TABULATED DATA

Table A.1 gives the specification limits for each property from Defence Standard 91–91 compared to the maxima and minima of the 2014 AVTUR data collected.

2.2 HISTOGRAMS AND TREND GRAPHS FOR ANNUAL MEAN RESULTS

Figures B.1 to B.49 are histograms and trend graphs. The histograms show the number of batches in each frequency class along with the percentage that this represents of the total number of batches included for that year. The trend graphs show the mean results for each property plotted against year for the period 1986 to 2014.

Where the labels on the x-axis of the histograms refer to a range of results, the label signifies the middle of the range. For example, the x-axis label '10' on the aromatics histogram (Figure B.3) includes a range of results from >9 to ≤11.

2.3 GRAPHS OF NEAR SPECIFICATION TRENDS FOR AVTUR PRODUCED FROM 1983 TO 2014

For seven specification properties, Figures B.50 to B.52 show the percentage of batches that have results near the specification limits, plotted against year for the period 1986 to 2014. The properties the figures relate to are listed here:

Figure B.50: Acidity, aromatics

Figure B.51: Mercaptan sulfur, flash point, freeze point

Figure B.52: Smoke point, naphthalenes

3 DISCUSSION

This section is a brief discussion of the results highlighting significant changes and points of interest for the aviation industry. It also gives some details on the limitations of the data.

The data for thermal stability, copper corrosion, and electrical conductivity are not discussed in this section for the reasons given in section 2.

BOCLE results should be reported for all batches containing more than 95 % hydroprocessed material, of which at least 20 % is severely hydroprocessed. However, it was not possible to establish if a BOCLE test was required for many batches as the refining process was not supplied[2]. No BOCLE results were reported for the batches used in this survey.

3.1 SAMPLE SIZE

Data from 1 488 batches were included in this report which represents 17 131 263 m^3 of AVTUR over the period from the start of 2014 to the end of 2014. This includes about 40 000 individual test results.

The data in the tables and histograms for some properties have been derived from fewer than the total number of batches because the specification, for a variety of reasons, detailed below, allows waivers (and in some cases the data provided had a small number of results unavailable).

3.2 TOTAL ACIDITY

The volume weighted mean value in 2014 was 0,0034 mg KOH/g and this has reduced over the last four years (Figure B.2). The percentage of batches 'near specification limit' has dropped to a 30 year low of 3 %.

A number of results were reported as '<0,001', for the purposes of this survey, they have been recorded as '0,0001'.

3.3 AROMATICS

The volume weighted mean value was 18,1 % v/v in 2014 (Figure B.3).

Aircraft operators are often concerned about the problems caused by different batches of fuel having large variations in aromatics. The aromatic content ranged from 11,2 % v/v to 25,0 % v/v with more than 99 % of batches in the range 13 % v/v to 25 % v/v. The small number of batches with very low aromatics (<5 % v/v) that were observed in the 2009 and 2010 surveys were not evident in this data set.

2 It should be noted that some of the data supplied for this survey were not in the form of test certificates, but were supplied in spreadsheet format. These electronic data do not always give all the data that would be given on the main batch test certificate. This lack of detailed information does not mean that the original certificate did not contain the correct information, nor does it suggest that the fuel did not comply with the requirements of Defence Standard 91–91.

3.4 TOTAL SULFUR

The volume weighted mean value of 0,057 % m/m (Figure B.5) shows an increase compared to 2013. There appears to be an upward trend since 1999. However, the mean has been variable in recent years and it is difficult to determine any definite trend. The sulfur content appears to show a multimodal distribution.

Defence Standard 91–91 allows several different methods for determining sulfur content. Some laboratories are using methods that can determine the sulfur content to three decimal places, whereas when older equipment/different test methods are used the result may only be reported to two decimal places. The most common test method used is IP 336 [27] which is reportable to the nearest 0,01 % m/m and the scope minimum is 0,03 % m/m. Therefore, many results are reported for batches with low sulfur contents as '<0,01 % m/m' and some as '<0,03 % m/m'. For the purposes of this report the results have been recorded without the 'less than' sign (to be consistent with previous surveys). The differing methods mean that it is not possible to accurately determine the number of batches with very low sulfur levels. The methodologies used and the way in which the sulfur content is reported may have an effect on the apparent mean value.

3.5 MERCAPTAN SULFUR

Mercaptan sulfur was reported for approximately two thirds of batches. Mercaptan sulfur is not required to be reported if the Doctor test is negative. A number of test certificates showed the mercaptan sulfur content as '<0,001'. For the purposes of this survey, these results have always been recorded as 0,001. This may affect the volume weighted mean value, which was 0,0008 % mass for 2014 (Figure B.7).

As mercaptan sulfur is often only reported after a positive doctor test is obtained, the calculated mean value in this report is likely to be higher than the true mean value.

3.6 DISTILLATION

The mean value for Initial Boiling Point (IBP) was 148,5 °C and is the lowest recorded since this record began in 1986 (Figure B.9). The mean values in 2014 for 10 % (166,9 °C) (Figure B.11), and 50 % (192,8 °C) (Figure B.13) recovered are also the lowest recorded. These three properties show a reducing trend.

The 2014 mean value for 90 % recovered of 233,8 °C is the lowest since 1986 but it is difficult to see a trend as the mean value has been variable in recent years (Figure B.16). The Final Boiling Point (FBP) mean of 257,9 °C shows no consistent trend (Figure B.18).

Only 10 % recovered and FBP have limits specified, which are 205 °C and 300 °C respectively. All results were within these limits.

Aviation turbine fuels containing synthesised hydrocarbons in accordance with ASTM D7566 [28] have extended requirements (over ASTM D1655 and Defence Standard 91–91) to ensure a sufficient distillation range[3]. The requirements are T50-T10, minimum of 15 °C, and

3 Although it is difficult to be certain due to the data received not being complete, with regard to refining processes, it is likely that few if any batches included in this survey contained synthetic components.

T90-T10[4], minimum of 40 °C. Of the 1 488 batches in 2014, two would not have met the T50-T10 requirement and one would not have met the T90-T10 requirement. The distribution of T50-T10 and T90-T10 results are shown in Figures B.19 and B.20.

3.7 FLASH POINT

The volume weighted mean value for flash point was 41,3 °C (Figure B.22). This is the lowest recorded since this record began in 1986 and there appears to be a reducing trend in the mean flash point since 1991. This trend is becoming less pronounced as the mean values approach the specification limit.

The 'near specification limit' analysis for flash point is shown in Figure B.51. 61 % of batches were 'near specification limit' in 2014 and there appears to be a rising trend in the number of flash point results near the specification limit. A precision study in 2008 led to the reproducibility of IP 170 being changed from 1,5° C to 3,2 °C. Although there has been a reduction in the mean and generally more batches near to the specification limit, the large changes seen in Figure B.51 are mostly due to the change in reproducibility.

The data indicate that flash point is a major restraining factor in jet fuel production.

3.8 DENSITY

The volume weighted mean for density was 799,6 kg/m^3 (Figure 23). This was the fourth year in a row that the mean has decreased. The minimum density was 781,5 kg/m^3. The specification limits are 775 kg/m^3 to 840 kg/m^3.

3.9 FREEZING POINT

The volume weighted mean value for 2014 of –54,6 °C is a slight increase from 2013. However, it is the second lowest value recorded since 1986 and there has been a slow downward trend since this time (Figure B.26).

The percentage of batches 'near specification limit' during 2014 was 8 %. There appears to be a decreasing trend in the number of batches near the specification limit. Nevertheless, freezing point appears to be a major restraining factor in jet fuel production for some refineries.

One batch was reported as <–60 °C, this was recorded as –60 °C for the purposes of this report.

3.10 KINEMATIC VISCOSITY

The volume weighted mean for 2014 was 3,61 cSt, which is the lowest recorded since 1986 (Figure B.28). There appears to be a reducing trend in mean viscosity and there has been a significant reduction since 2010.

4 T10, T50, and T90 are the distillation temperatures at 10 %, 50 %, and 90 % recovered respectively.

The specification limit is 8 cSt maximum at –20 °C. However, it should be noted that most aircraft engines are certified with a maximum viscosity of 12 cSt at –40 °C[5]. This is approximately equivalent to 5,5 cSt at –20 °C. There were no batches that exceeded 5,5 cSt in 2014, the maximum was 4,747 cSt.

3.11 SPECIFIC ENERGY

The volume weighted mean was 43,24 MJ/kg in 2014 and represents little change compared to recent years. Figure B.30 shows no particular trend in mean value. Results are almost all between 43,0 MJ/kg and 43,5 MJ/kg. The specification minimum is 42,80 MJ/kg.

3.12 SMOKE POINT

The volume weighted mean for 2014 was 23,5 mm which was the fourth consecutive annual increase. The smoke point specification limit was[6] 19 mm minimum.

The histogram shows an unusual distribution with regard to the high percentage of results at 25 mm. This may be linked to the specification requirement for the measurement of naphthalenes when the smoke point is less than 25 mm.

3.13 NAPHTHALENES

Not all batches had naphthalenes results reported as the specification only requires the determination of naphthalene content if the smoke point is less than 25 mm.

The mean for 2014 was 1,31 % vol, one of the lowest recorded since records began in 1986. There appears to be a downward trend since 1988 (Figure B.34). The specification limit is 3 % vol maximum.

As naphthalene content is often only reported after a low smoke point result is obtained, the calculated mean value in this report is likely to be higher than the true mean value.

3.14 EXISTENT GUM

For more than 95 % of batches, the existent gum results were reported as 0, <1, or 1 mg/100 ml. For results reported as 0 or <1, a value of 1 has been recorded in the histograms. The 2014 mean value was 1,0 mg/100 ml as shown in Figure 35. The precision for existent gum is very poor; it is likely that all batches contain virtually no gum and the range of results (up to a maximum of 5 mg/100 ml) is due to the test precision. The vast majority of the results are well below the 7 mg/100 ml maximum specification limit. There is no significant trend in mean value for existent gum.

5 The requirement for 12 cSt is particularly relevant for APUs which may need to be started at altitude after cold soak conditions. Some APUs are flight critical.

6 Recent changes to Defence Standard 91–91 include a new smoke point limit of 18 mm minimum. The data collected for this report were produced before this change.

3.15 MICROSEPAROMETER®

The 2014 mean MSEP® value of 93,0 has changed little compared to the previous few years (Figure B.38).

The Defence Standard 91–91 limits for MSEP® rating is a minimum of 85 without SDA, or 70 with SDA due to the over-sensitivity of the test method to SDA (Stadis 450). Some MSEP® values during 2014 were reported outside the specification limits. The reported failures may not be at the point of manufacture and downstream of this point a low MSEP® is not used as the sole reason for rejection of a fuel. One result of higher than 100 (102) was reported.

3.16 PARTICULATE CONTAMINATION

This is a relatively new requirement for Defence Standard 91–91 with a maximum limit of 1 mg/l. The 2014 volume weighted mean value of 0,25 is similar to that recorded in recent years (Figure B.40). A number of batches did not include results for this property. Most of these batches were imported fuel and it is assumed that this testing was carried out at point of manufacture as required by the specification. No results outside the specification limit were reported.

3.17 SAYBOLT COLOUR

This is a relatively new requirement for Defence Standard 91–91. The 2014 volume weighted mean value is 26,6 and has changed little in recent years (Figure B.42). Results reported as '>30' have been recorded as '30' for the purposes of this report.

3.18 PARTICLE COUNTS

For ease of producing histograms, ISO codes [29] have been used to indicate particle numbers[7]. Histograms show the distribution of ISO codes for ≥4 μm, ≥6 μm, ≥14 μm, ≥21 μm, ≥25 μm, and ≥30 μm channels. For low particle counts (and low ISO codes) repeatability is poor and many labs report ISO codes below 7 in a variety of ways. For the purposes of this report any value of less than 7 was recorded as 7.

The mean values over the period of 2009 to 2014 are shown in Figure 49. Particle counts showed a slight drop in 2014 but no trends are apparent. No specification limits for this property have been set at this time.

3.19 BOCLE

There were no BOCLE results reported in 2014.

7 According to ISO 4406, codes are applicable to the ≥4 μm, ≥6 μm, and ≥14 μm channels. However, for the purposes of Defence Standard 91–91, codes are reported using the same ISO 4406 coding table, for all six channels.

3.20 NEAR SPECIFICATION TRENDS

Figures B.50 to B.52 are graphs showing the percentage of batches with test results near the specification limit, against year, for seven specification properties.

The properties with the highest percentage of batches with results near the specification limit in 2014 were flash point (61 %) and smoke point (32 %). It should be noted that the new precision for flash point (IP 170) has significant effects on the number of batches near specification limit as mentioned in 3.7.

4 SUMMARY OF CHANGES AND TRENDS

4.1 TREND DATA

Table 1: Properties where the mean value shows increasing or decreasing trends

Properties where the mean value has a rising trend	Properties where the mean value has a decreasing trend
Flash Point batches near specification limit (increasing since 1991)	Distillation IBP (decreasing since 1991)
	Distillation 10 % Recovery (decreasing since 1991)
	Distillation 50 % Recovery (decreasing since 2010)
	Flash Point (decreasing since 1991)
	Freezing Point and freezing point batches near specification limit (decreasing since 1988)
	Viscosity (decreasing since 1991)
	Naphthalenes (decreasing since 1988)

4.2 SIGNIFICANT CHANGES IN 2014

Table 2: Significant changes in mean values

Property	Change
Distillation, IBP	Down 2,3 °C since 2009 (mean is at the lowest level since records began in 1986)
Distillation, 10 % Recovered	Down 4,2 °C since 2010 (mean is at the lowest level since records began in 1986)
Distillation, 50 % Recovered	Down 4,5 °C since 2010 (mean is at the lowest level since records began in 1986)
Flash Point	Down 1,3 °C since 2010 (mean is at the lowest level since records began in 1986)
Viscosity	Down 0,30 mm^2/s since 2010 (mean is at the lowest level since records began in 1986)

5 ACKNOWLEDGEMENTS

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ANNEX A
RESULTS SUMMARIES

A.1 2014 – DATA FROM 1 488 BATCHES OF JET FUEL REPRESENTING 17 131 263 M^3

Table A.1: Minima and maxima for 2014 data and specification limits

Method	Def Stan 91–91 Specification limits		Results summary 2014		
	Min	Max	Min	Max	Mean
Total acidity, mg KOH/g	–	0,015	0,000	0,015	0,0034
Aromatics, % volume	–	25,0[8]	11,2	25,0	18,1
Total sulfur, % mass	–	0,30	0,0005	0,2200	0,057
Mercaptan sulfur, % mass	–	0,0030	0,0001	0,0026	0,0008
Distillation IBP, °C	Report		137,8	162,4	148,5
10 % Recovery, °C	–	205,0	159,2	182,2	166,9
50 % Recovery, °C	Report		171,1	209,4	192,8
90 % Recovery, °C	Report		193,7	250,5	233,8
FBP, °C	–	300,0	230,8	297,4	257,9
Flash Point, °C	38,0	–	38,0	49,5	41,3
Density @ 15 °C, kg/m^3	775,0	840,0	781,8	818,5	799,6
Freezing Point, °C	–	–47,0	–75,8	–47,0	–54,6
Viscosity @ –20 °C, mm^2/s	–	8,00	2,937	4,747	3,61
Specific energy, net MJ/kg	42,80	–	42,92	43,49	43,24
Smoke point, mm	19,0	–	19,0	29,0	23,54
Naphthalenes, % volume	–	3,00	0,05	3,03	1,31
Existent gum, mg/100 ml	–	7	0	5	1,07
MSEP®	85 (70 with SDA)	–	61	102	93,0
BOCLE, mm	–	0,85	n/a	n/a	n/a
Particulate, mg/l	–	1,0	0,00	1,00	0,25
Colour	Report		10	30	26,6

8 The limit is 26,5 if using IP 436. All results have been converted to IP 156 equivalent data.

Table A.1: Minima and maxima for 2014 data and specification limits (continued)

Method	Def Stan 91–91 Specification limits		Results summary 2014		
	Min	**Max**	**Min**	**Max**	**Mean**
Particle count,					
≥4 μm	Report		10	22	16,3
≥6 μm	Report		8	20	14,2
≥14 μm	Report		7	17	9,6
≥21 μm	Report		7	16	8,3
≥25 μm	Report		7	15	7,8
≥30 μm	Report		7	13	7,4

ANNEX B
FIGURES

B.1 TOTAL ACIDITY

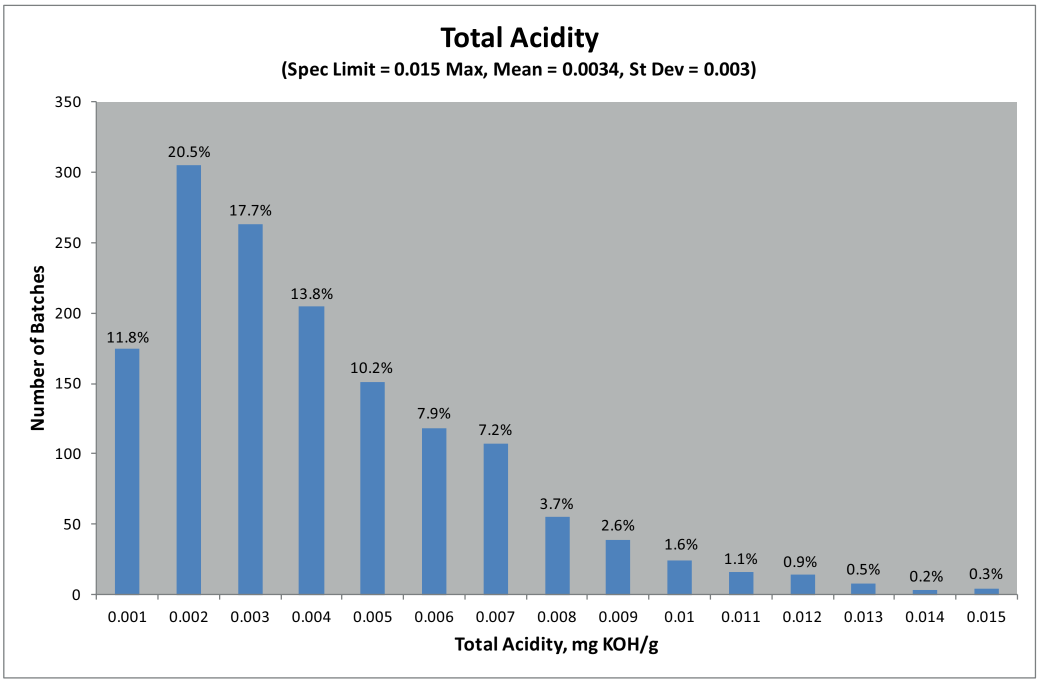

Figure B.1: Total acidity histogram

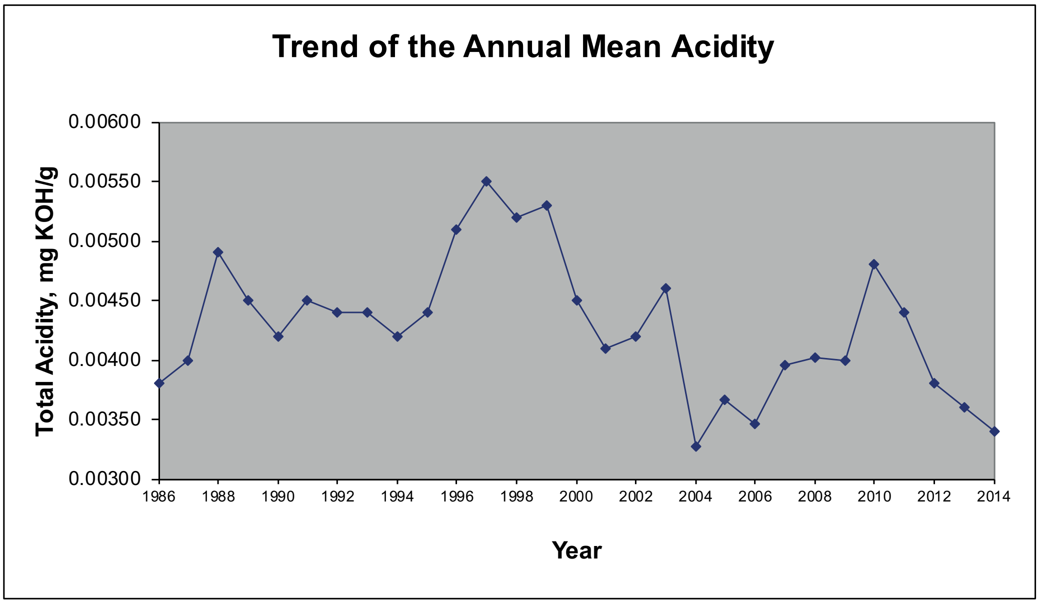

Figure B.2: Total acidity trend graph

B.2 AROMATICS

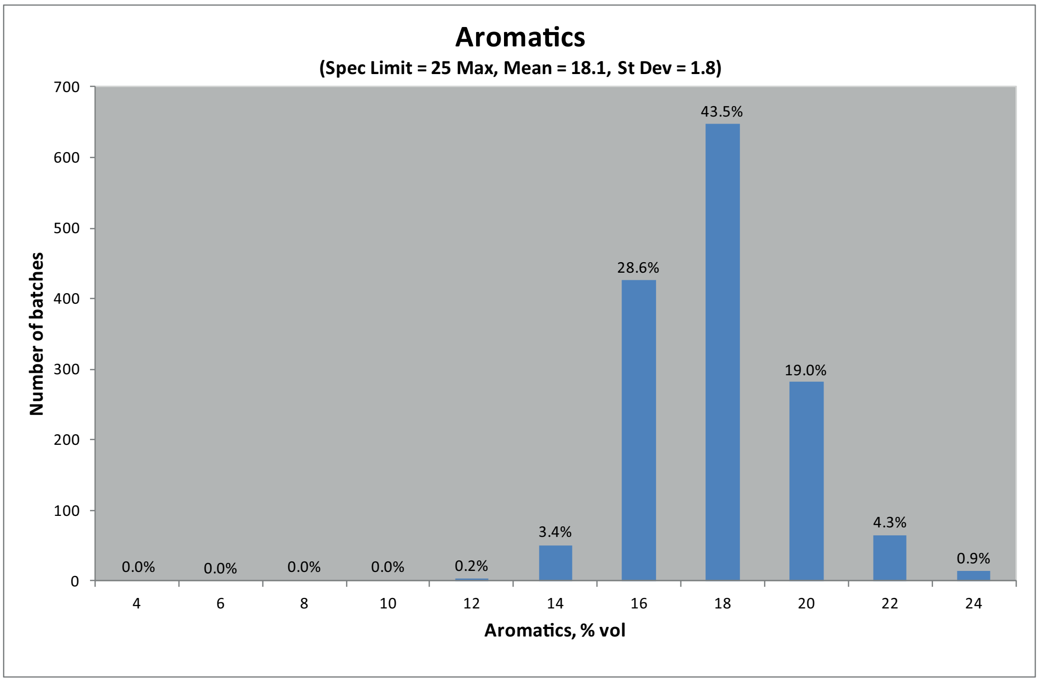

Figure B.3: Aromatics histogram

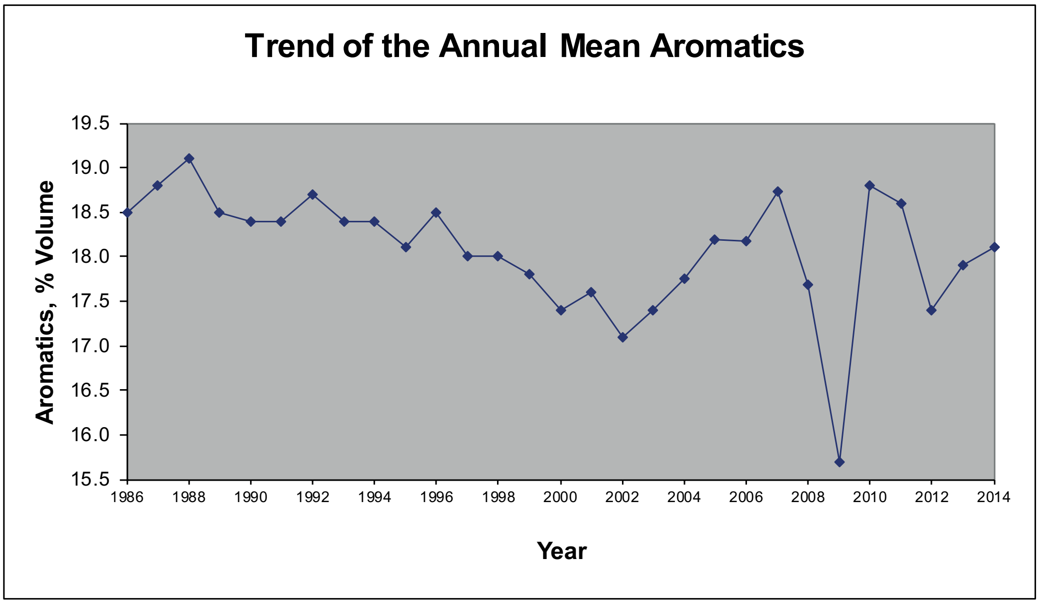

Figure B.4: Aromatics trend graph

B.3 TOTAL SULFUR

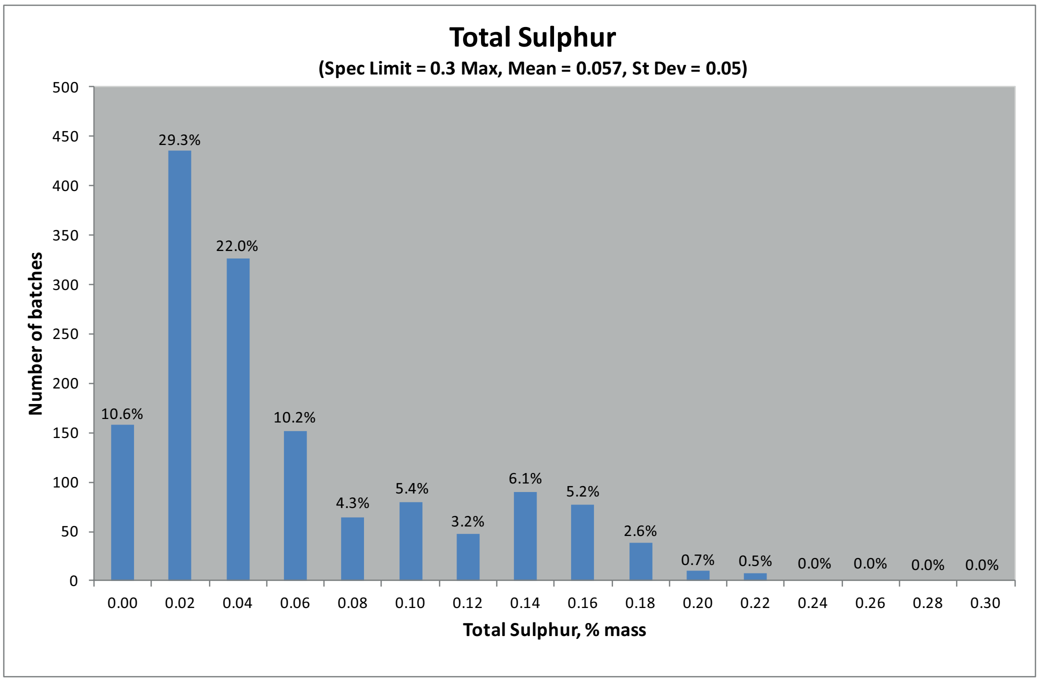

Figure B.5: Total sulfur histogram

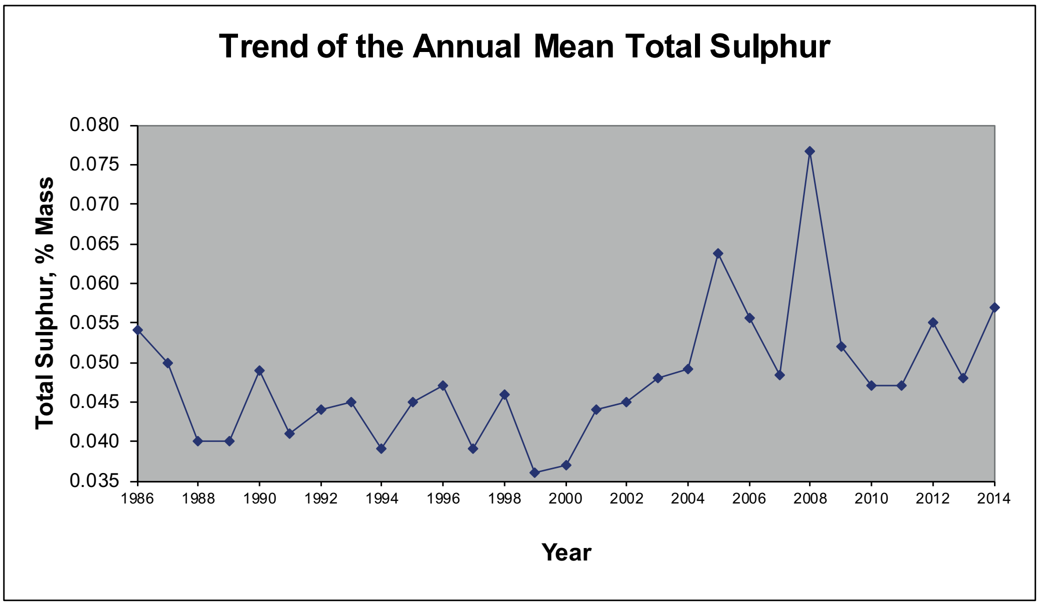

Figure B.6: Total sulfur trend graph

B.4 MERCAPTAN SULFUR

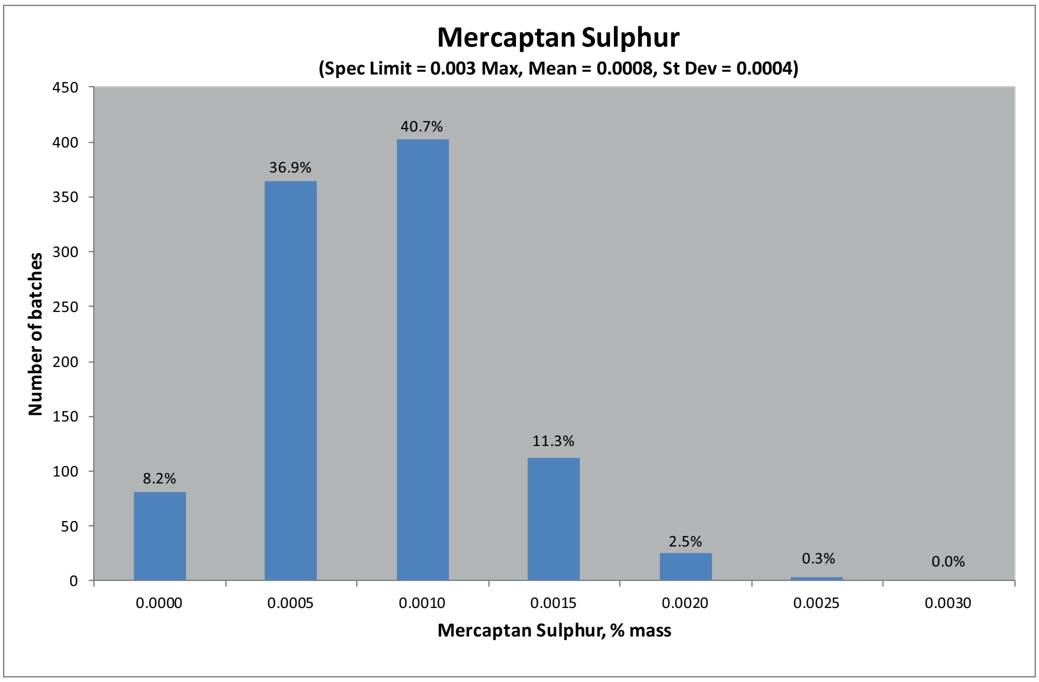

Figure B.7: Mercaptan sulfur histogram

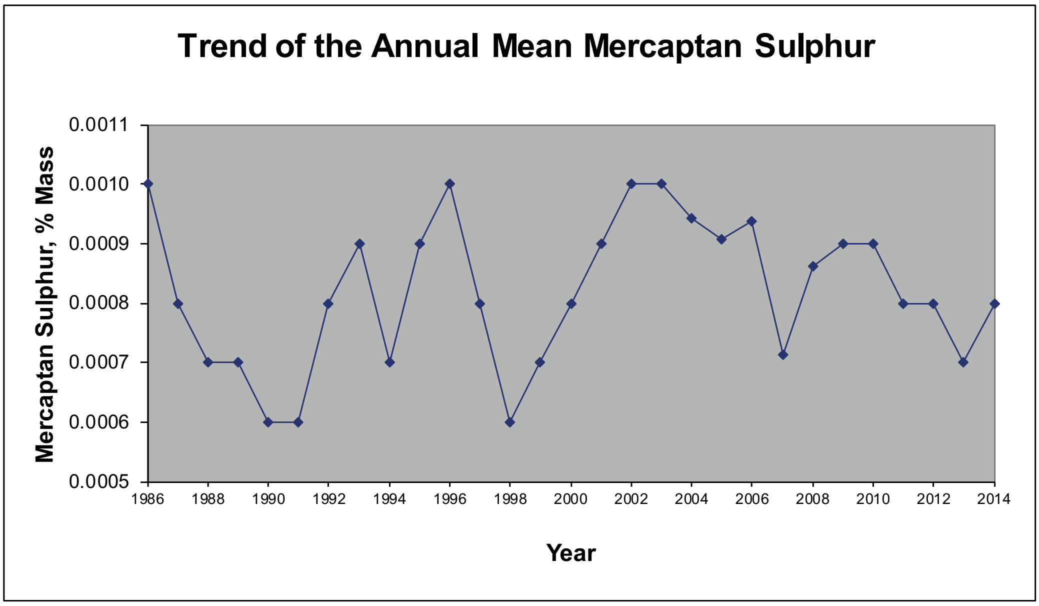

Figure B.8: Mercaptan sulfur trend graph

B.5 DISTILLATION IBP

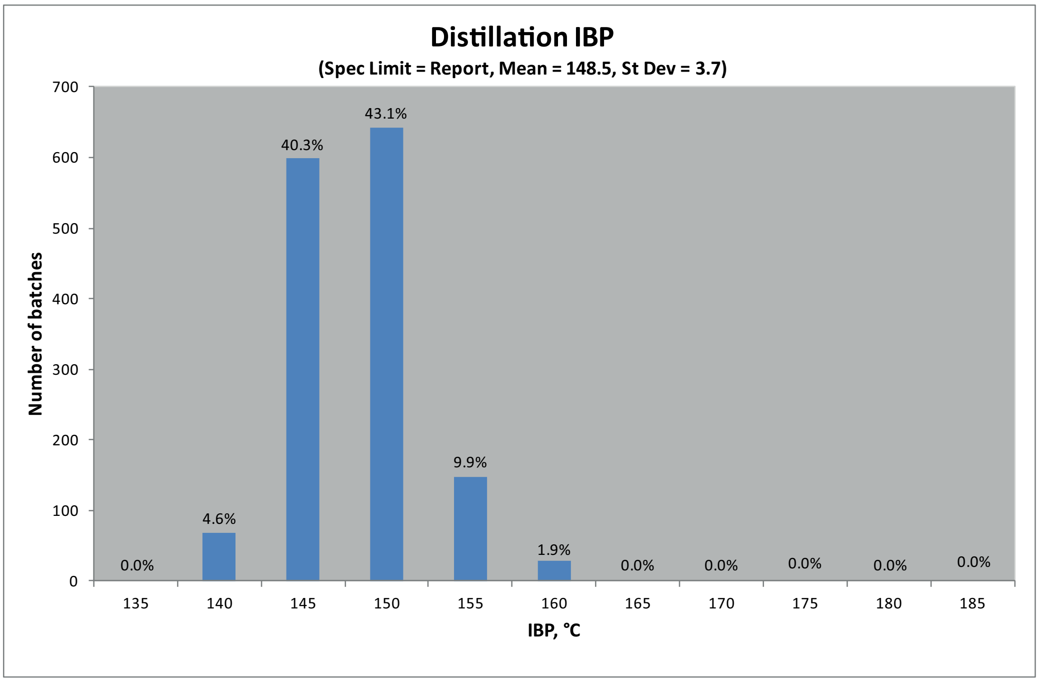

Figure B.9: Distillation IBP histogram

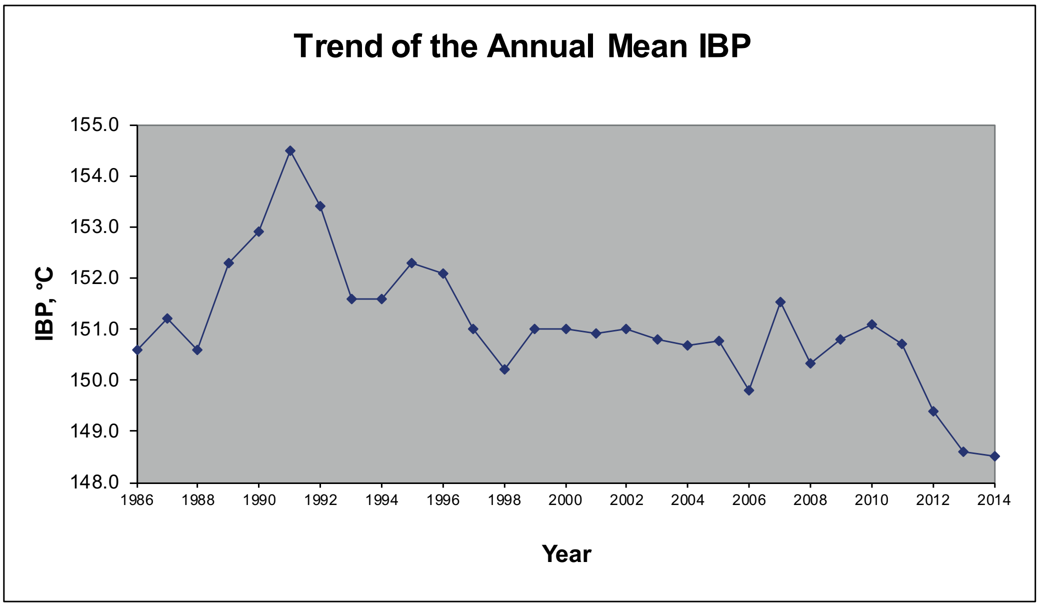

Figure B.10: Distillation IBP trend graph

B.6 DISTILLATION 10 % RECOVERY

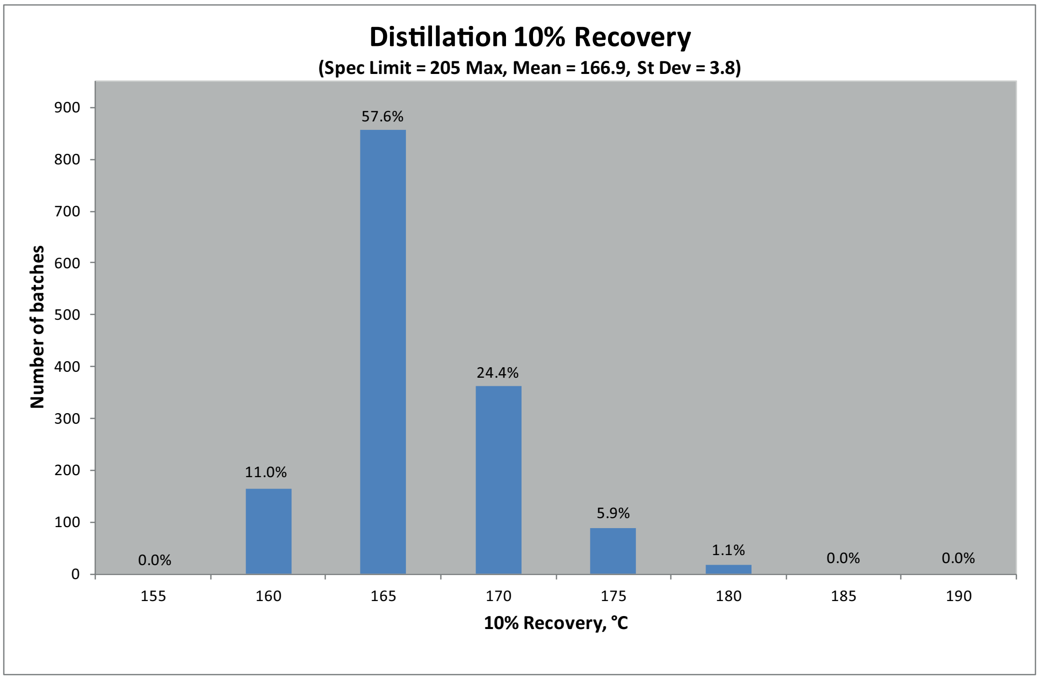

Figure B.11: Distillation 10 % recovery histogram

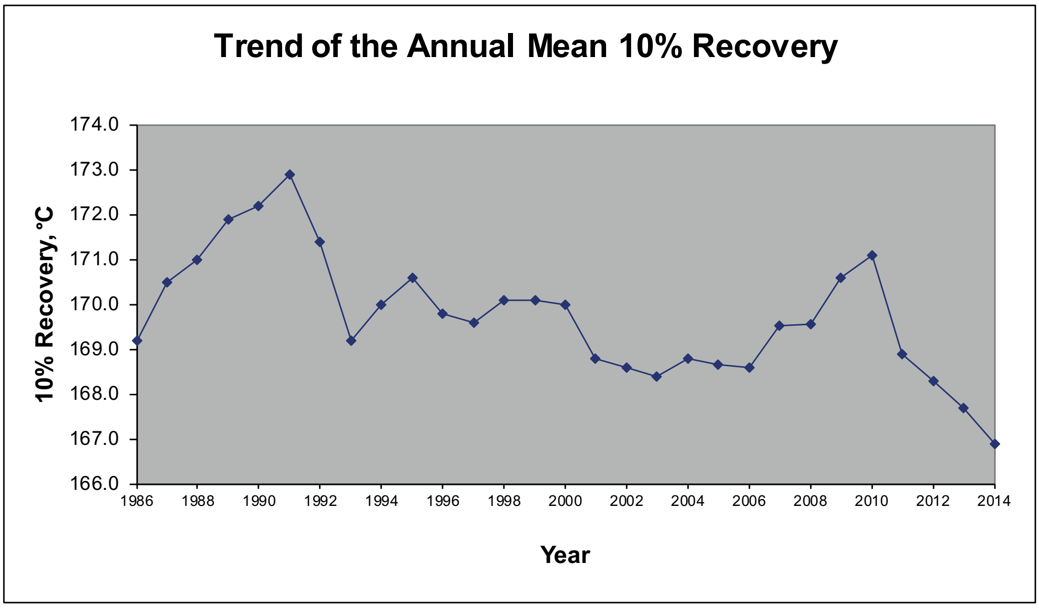

Figure B.12: Distillation 10 % recovery trend graph

B.7 DISTILLATION 50 % RECOVERY

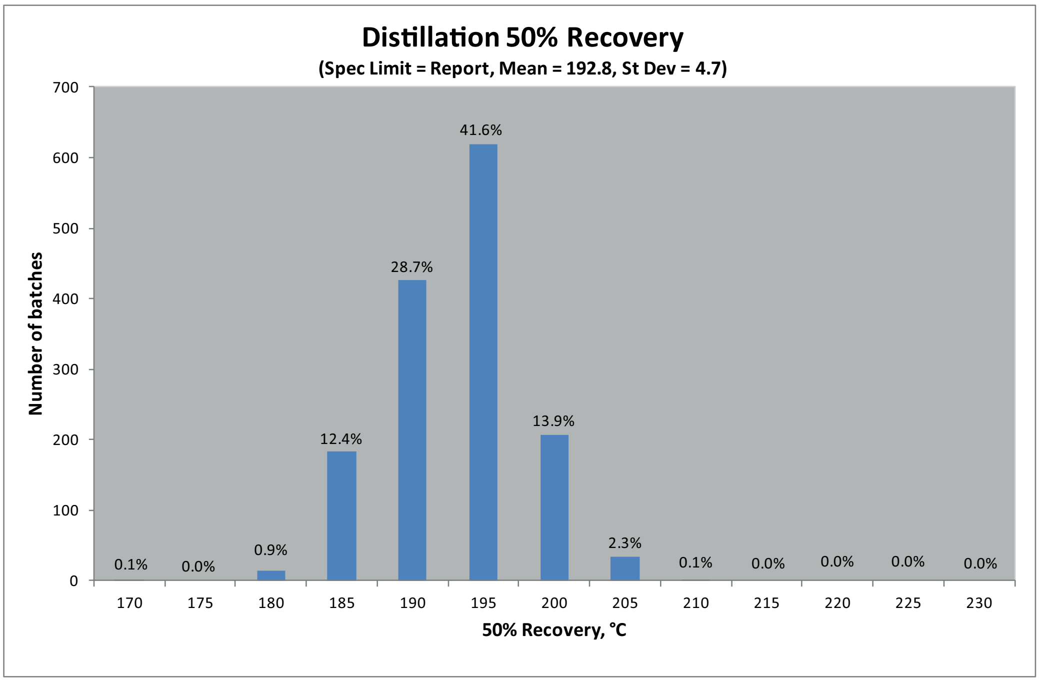

Figure B.13: Distillation 50 % recovery histogram

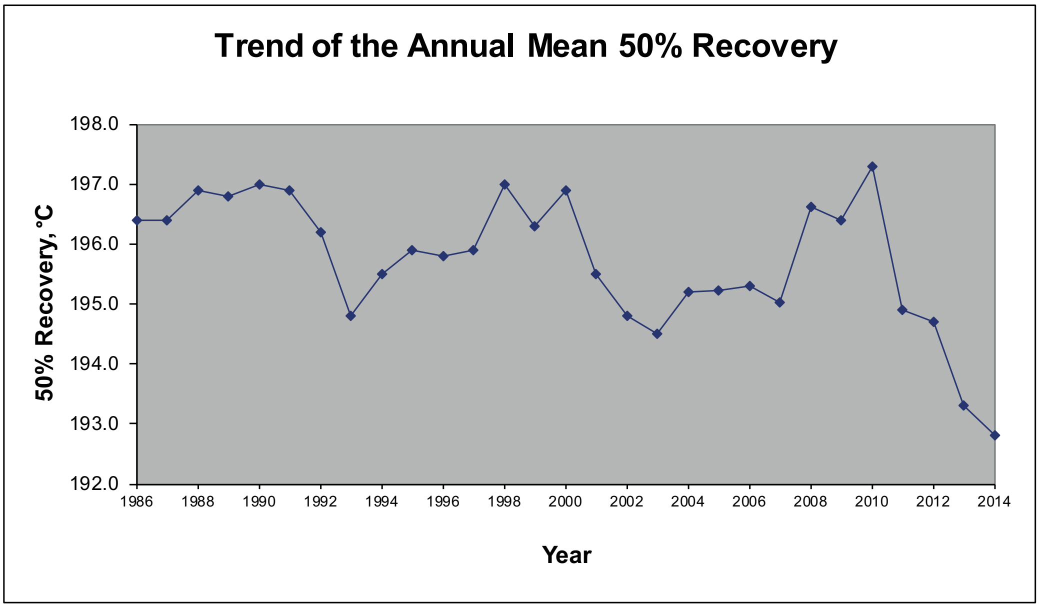

Figure B.14: Distillation 50 % recovery trend graph

B.8 DISTILLATION 90 % RECOVERY

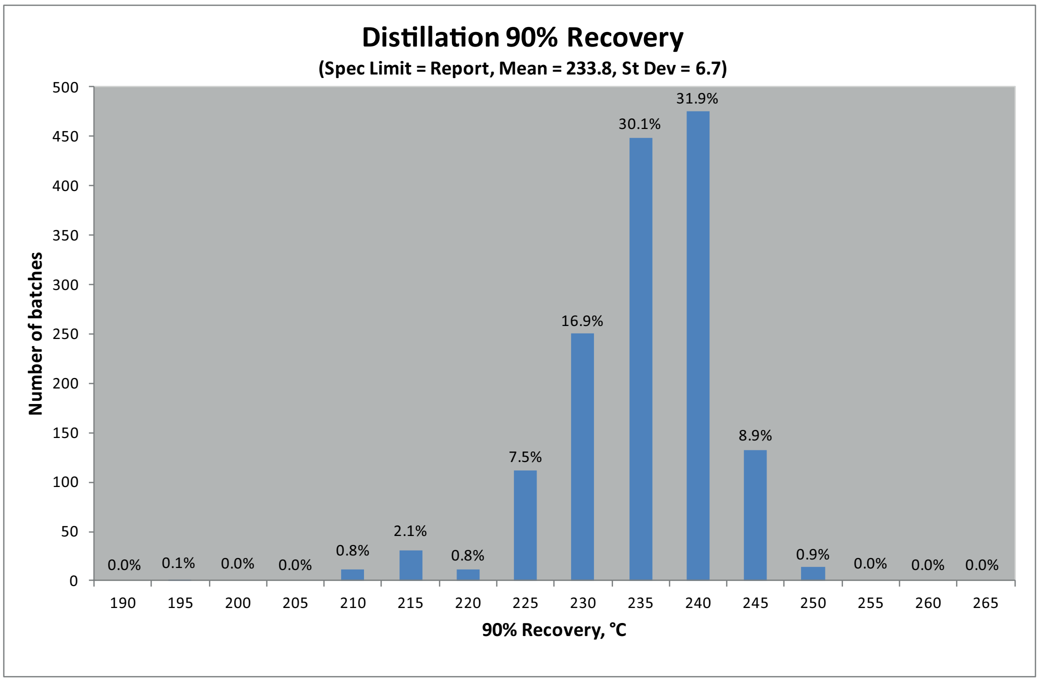

Figure B.15: Distillation 90 % recovery histogram

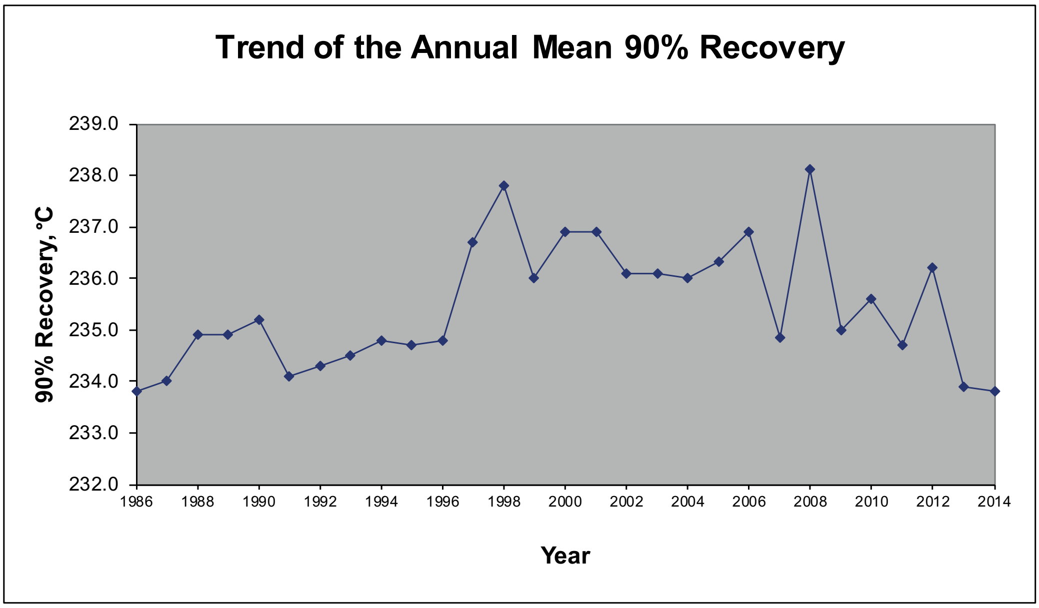

Figure B.16: Distillation 90 % recovery trend graph

B.9 DISTILLATION FBP

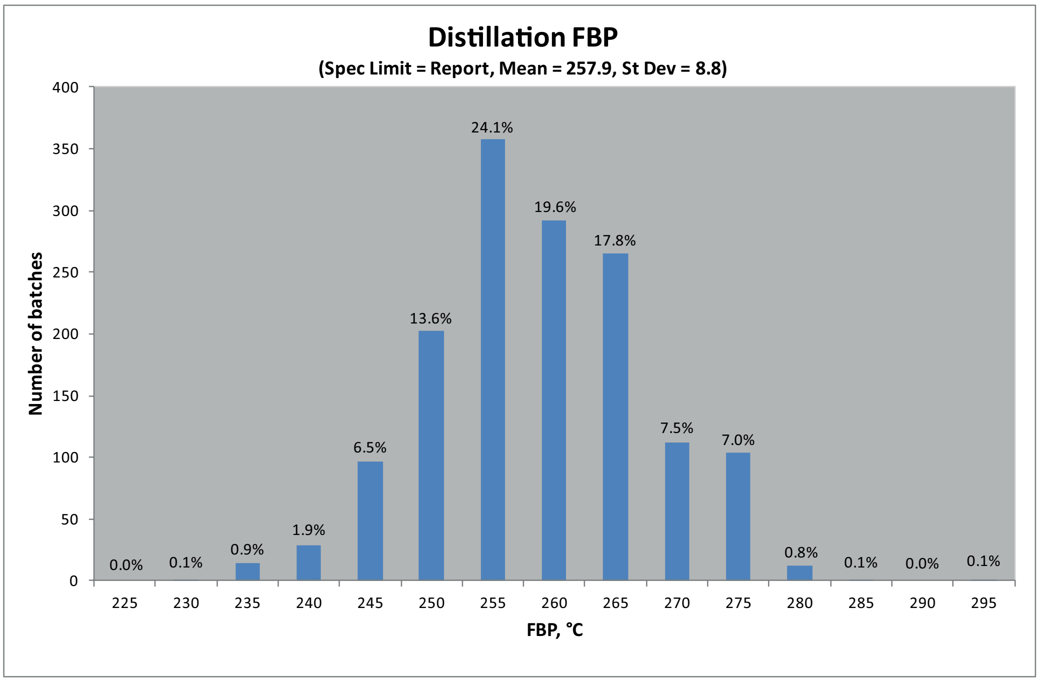

Figure B.17: Distillation FBP histogram

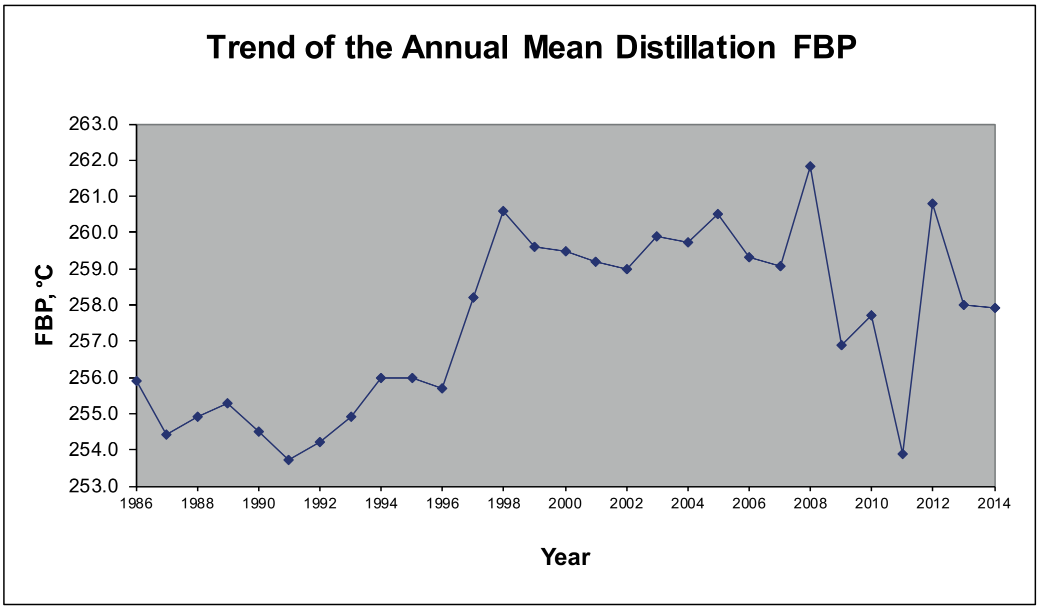

Figure B.18: Distillation FBP trend graph

B.10 DISTILLATION RANGE

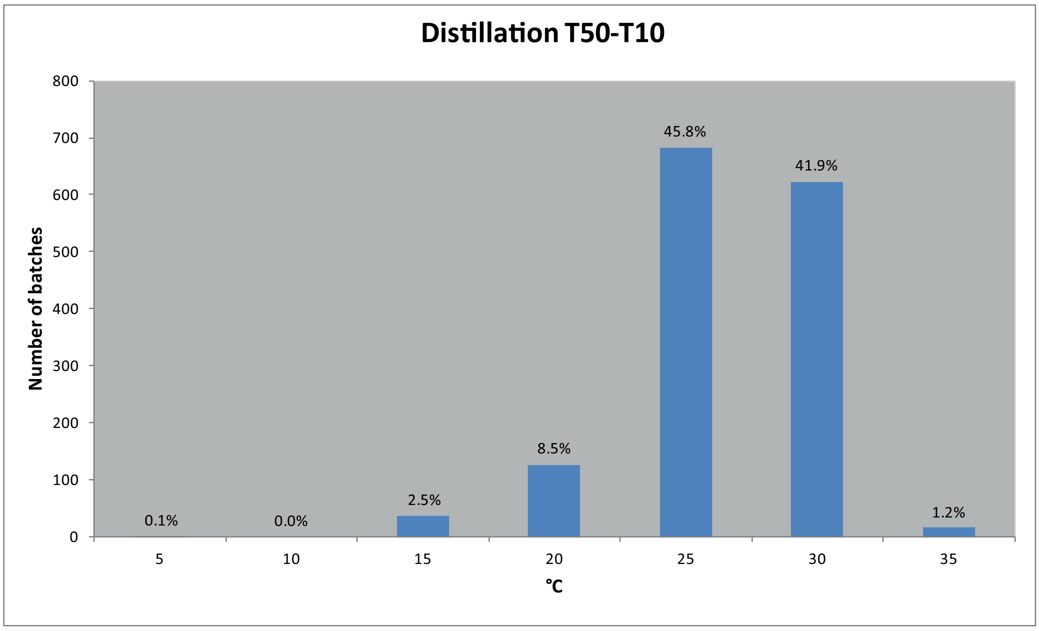

Figure B.19: Distillation T50-T10

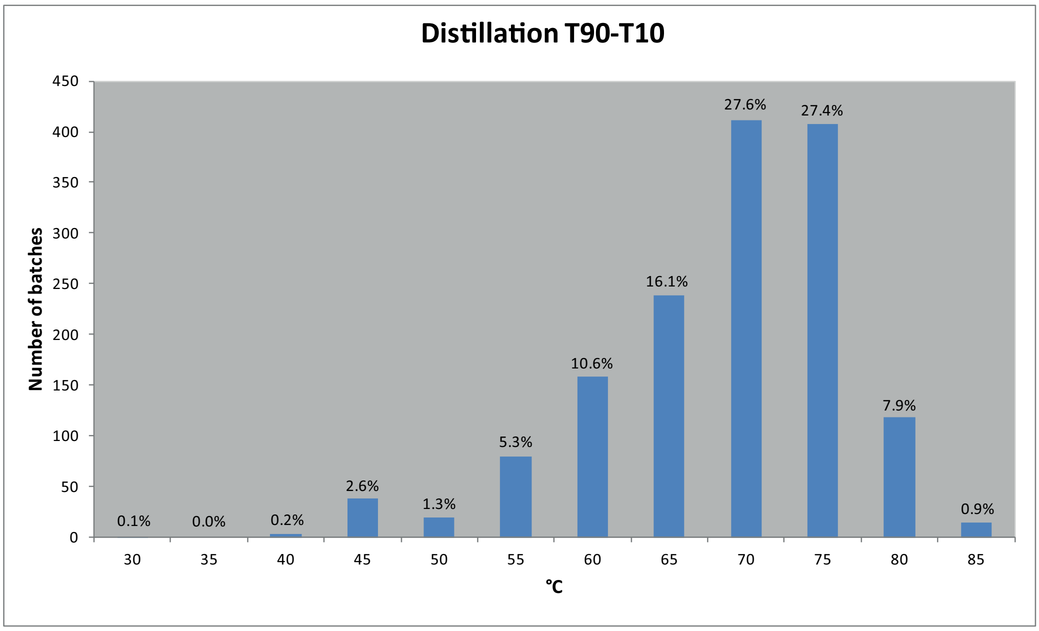

Figure B.20: Distillation T90-T10

B.11 FLASH POINT

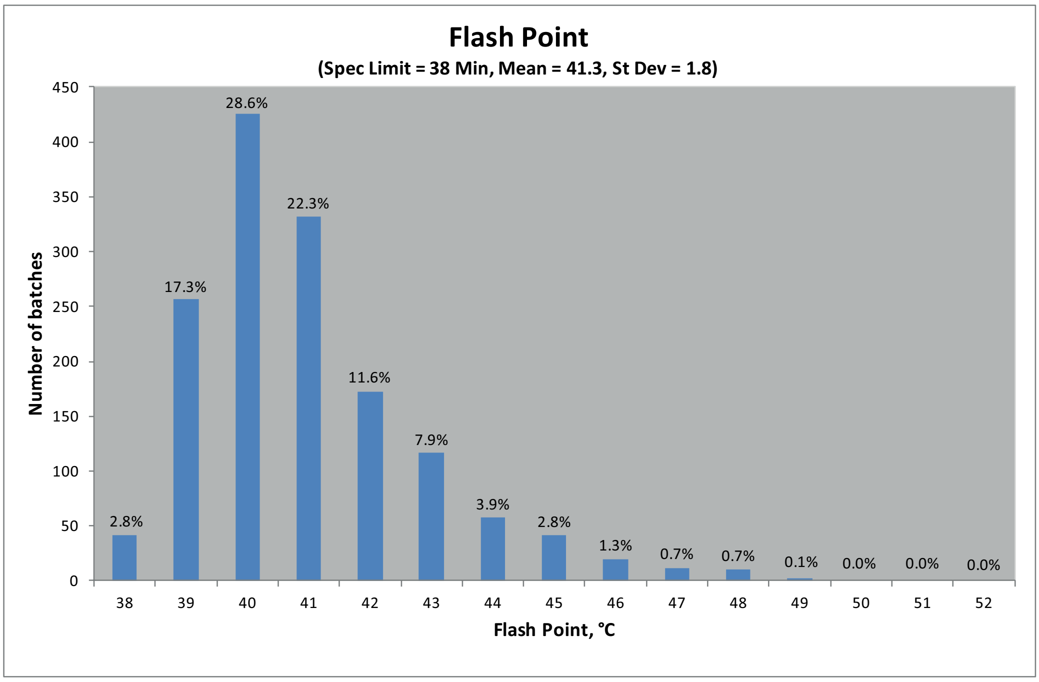

Figure B.21: Flash point histogram

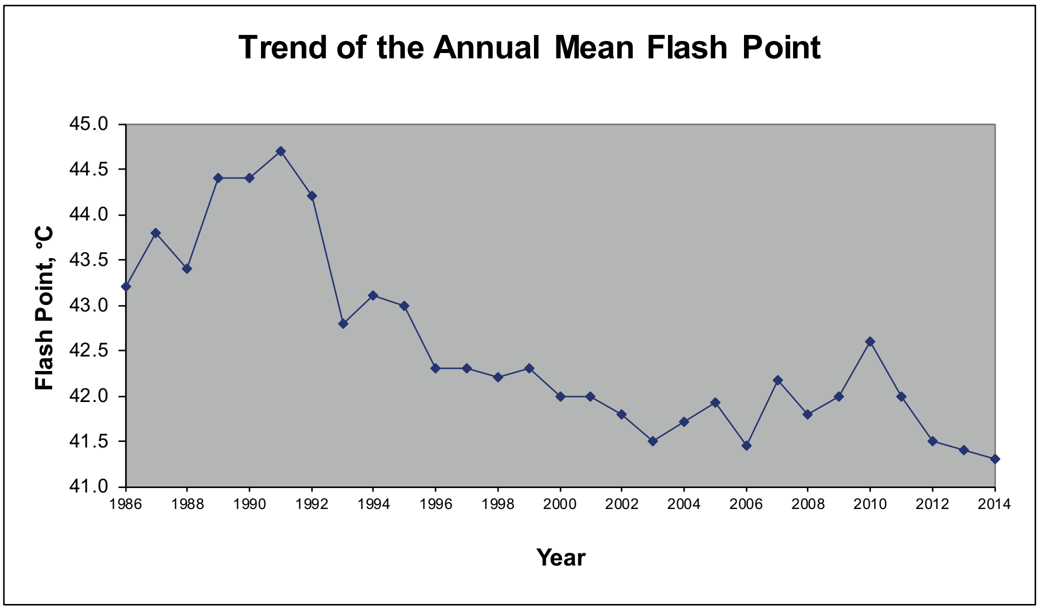

Figure B.22: Flash point trend graph

B.12 DENSITY AT 15 °C

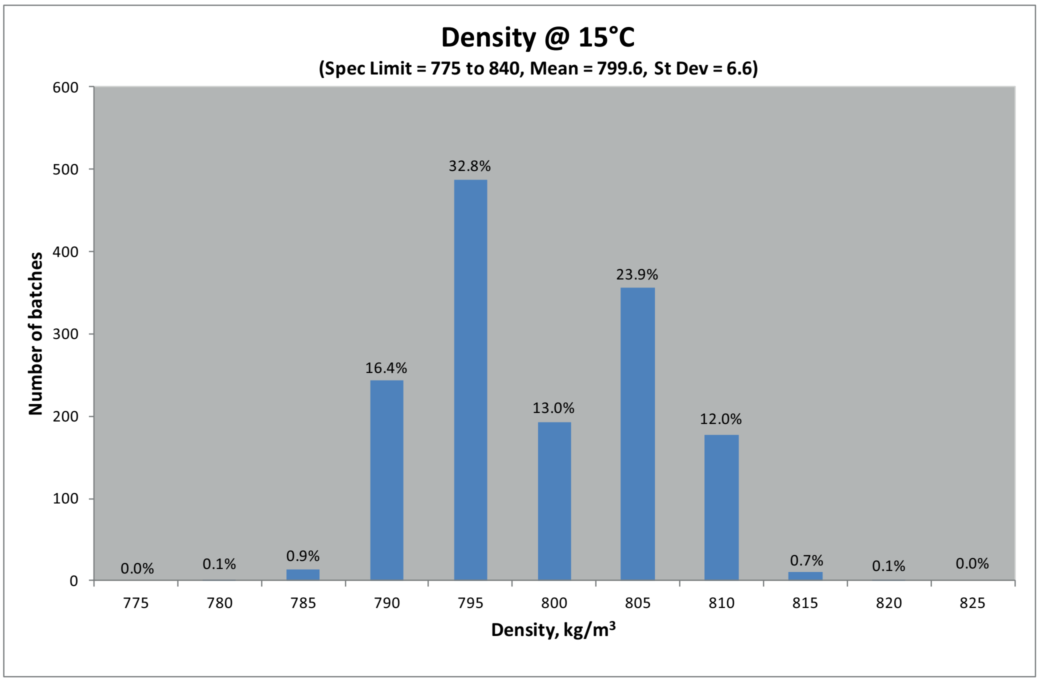

Figure B.23: Density histogram

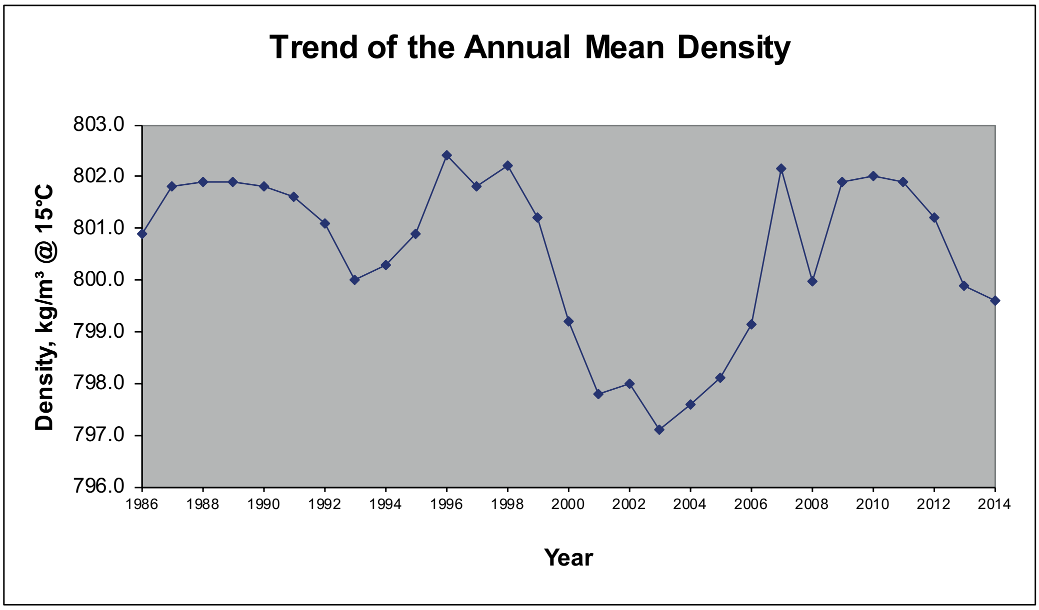

Figure B.24: Density trend graph

B.13 FREEZING POINT

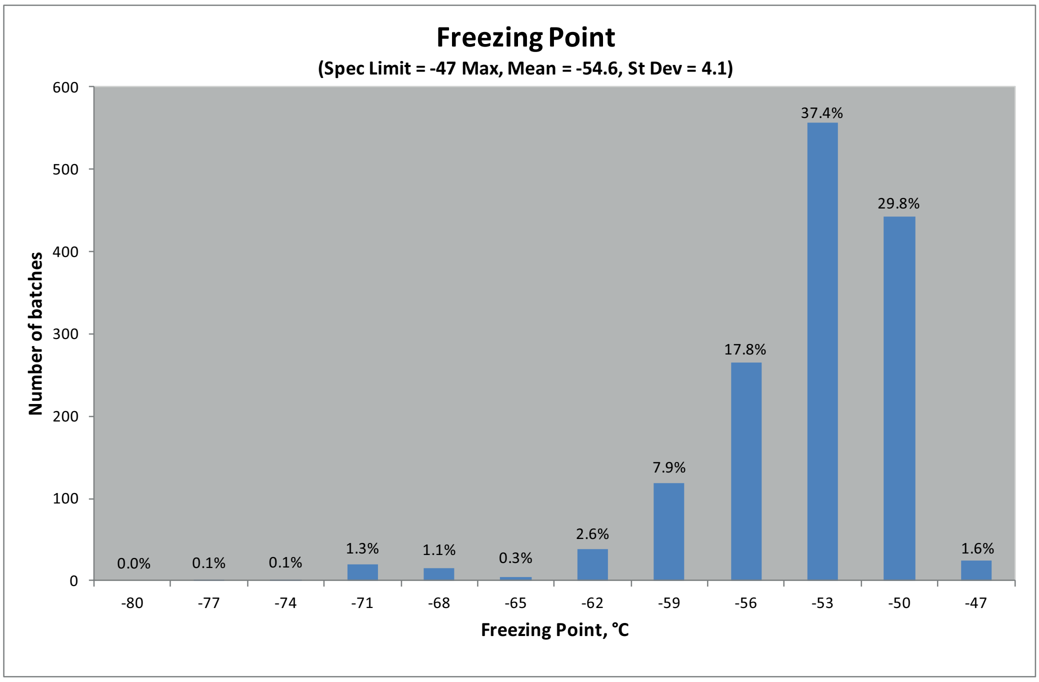

Figure B.25: Freezing point histogram

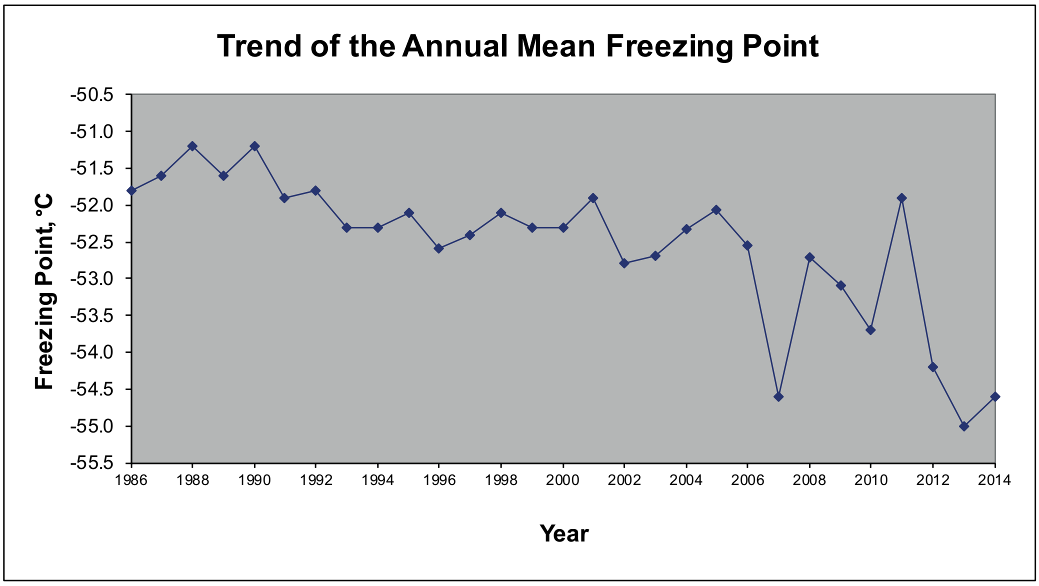

Figure B.26: Freezing point trend graph

B.14 KINEMATIC VISCOSITY AT –20 °C

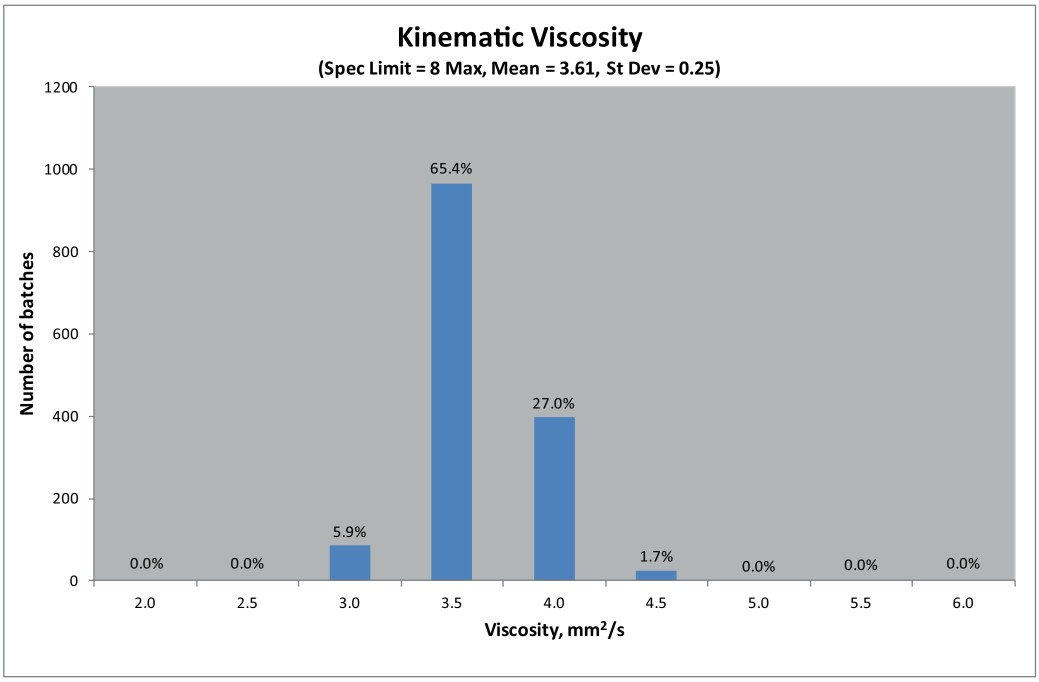

Figure B.27: Kinematic viscosity histogram

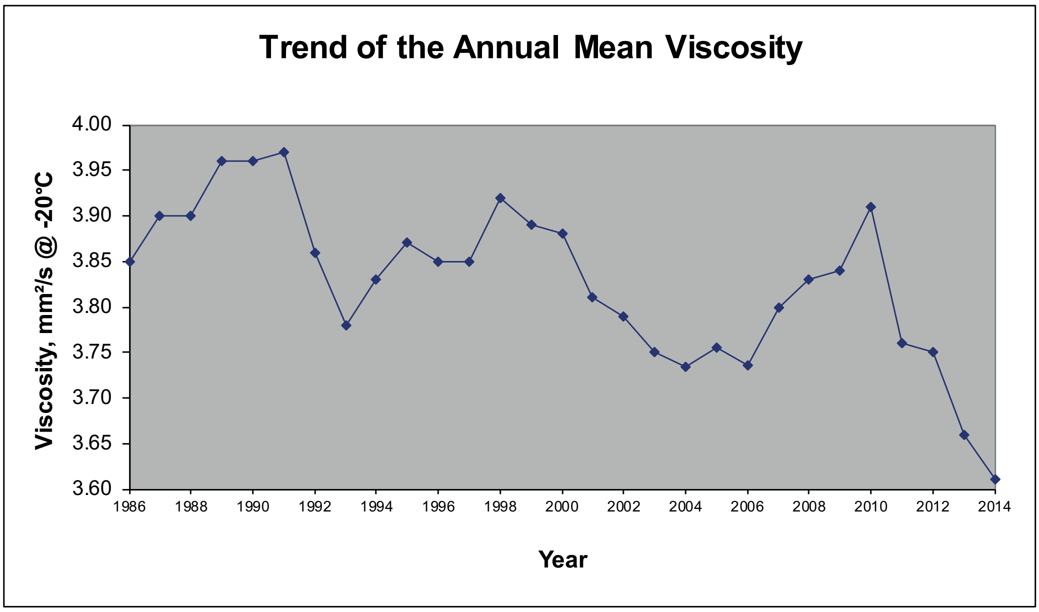

Figure B.28: Kinematic viscosity trend graph

B.15 SPECIFIC ENERGY

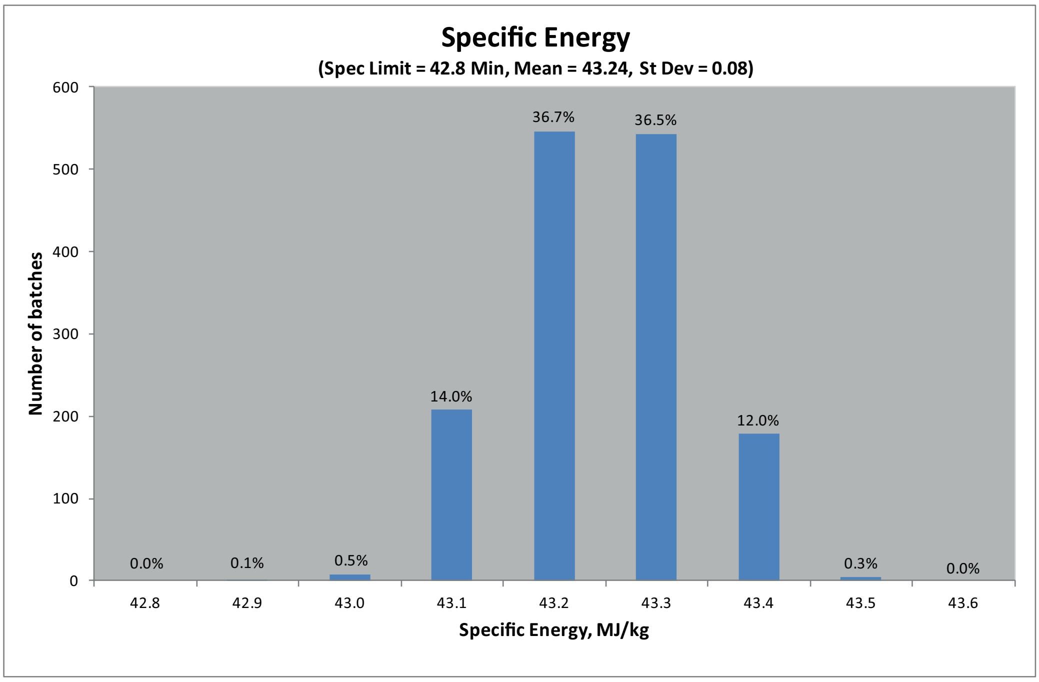

Figure B.29: Specific energy histogram

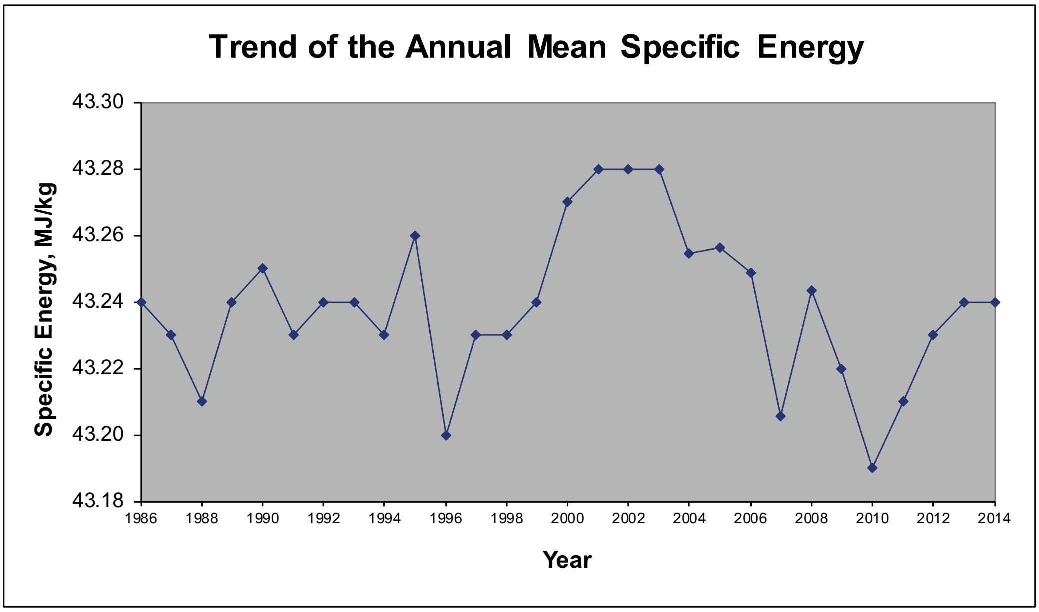

Figure B.30: Specific energy trend graph

B.16 SMOKE POINT

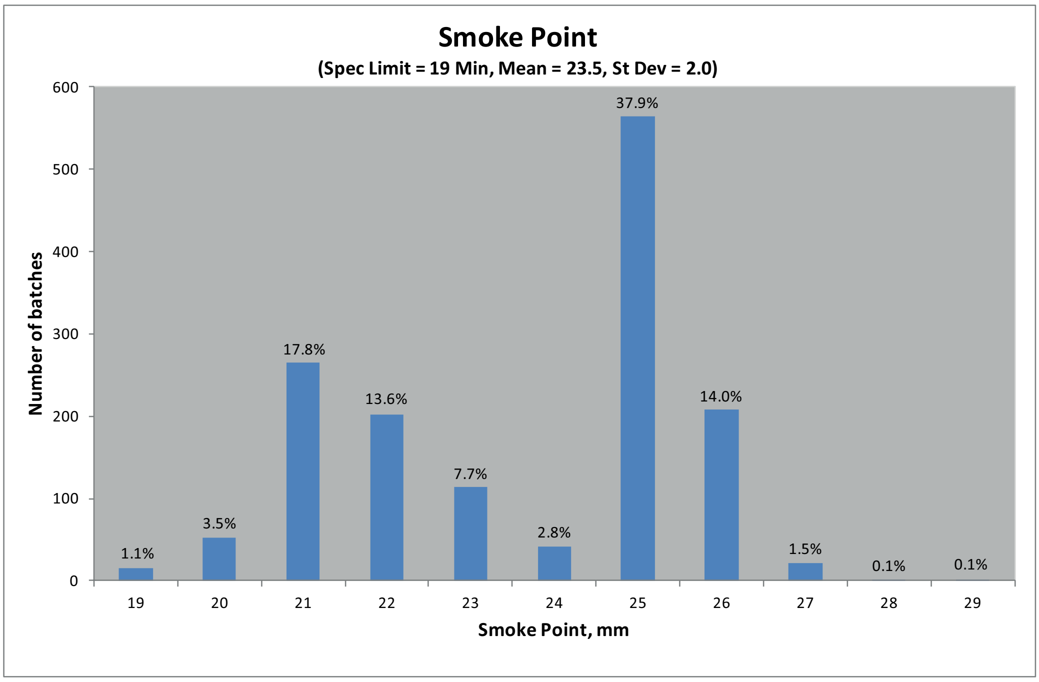

Figure B.31: Smoke point histogram

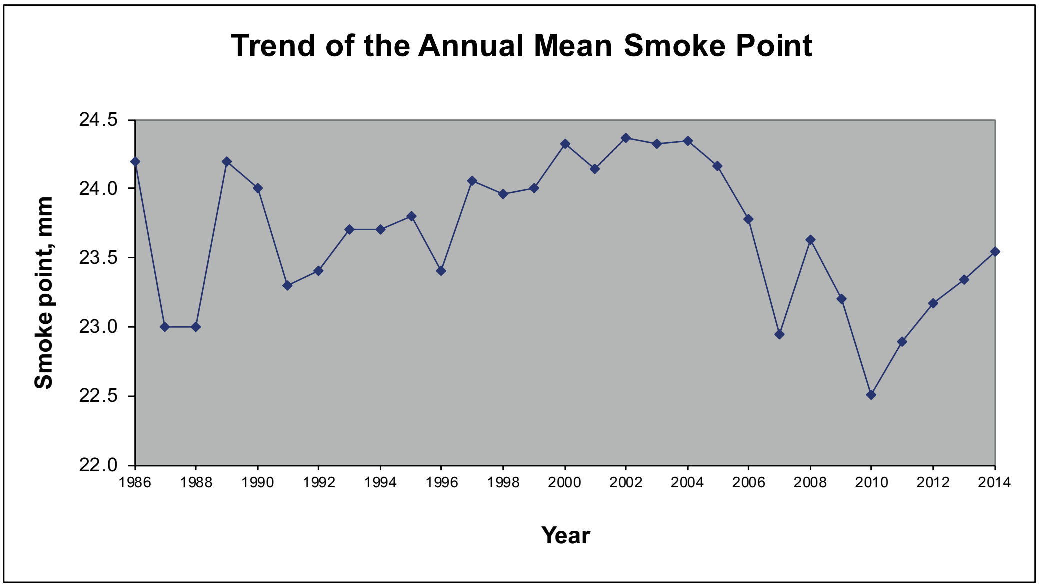

Figure B.32: Smoke point trend graph

B.17 NAPHTHALENES

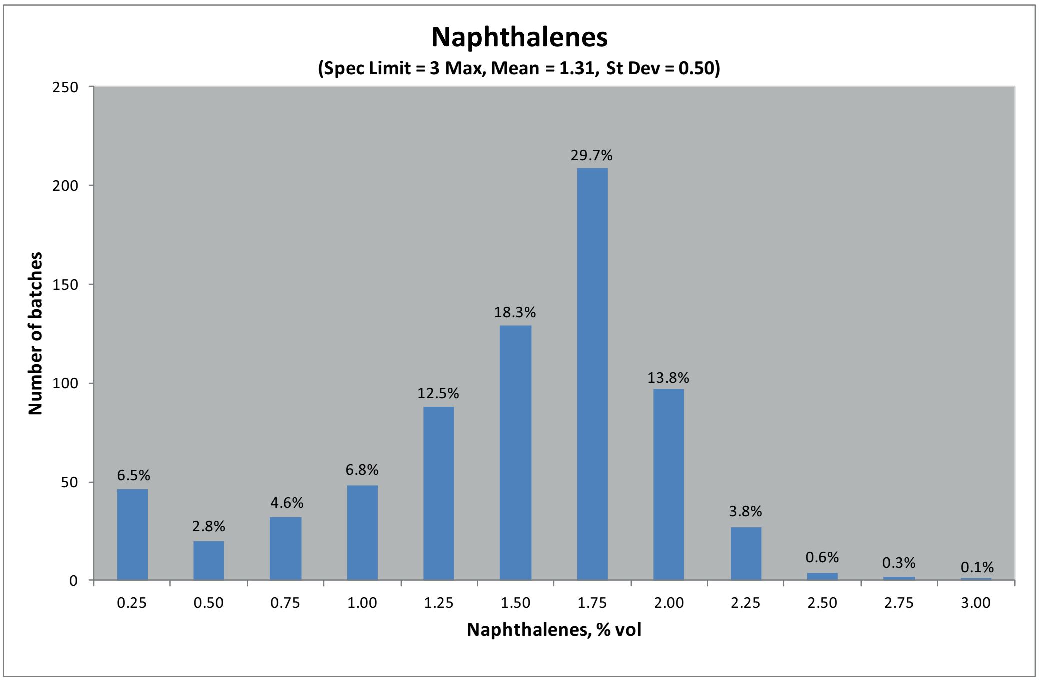

Figure B.33: Naphthalenes histogram

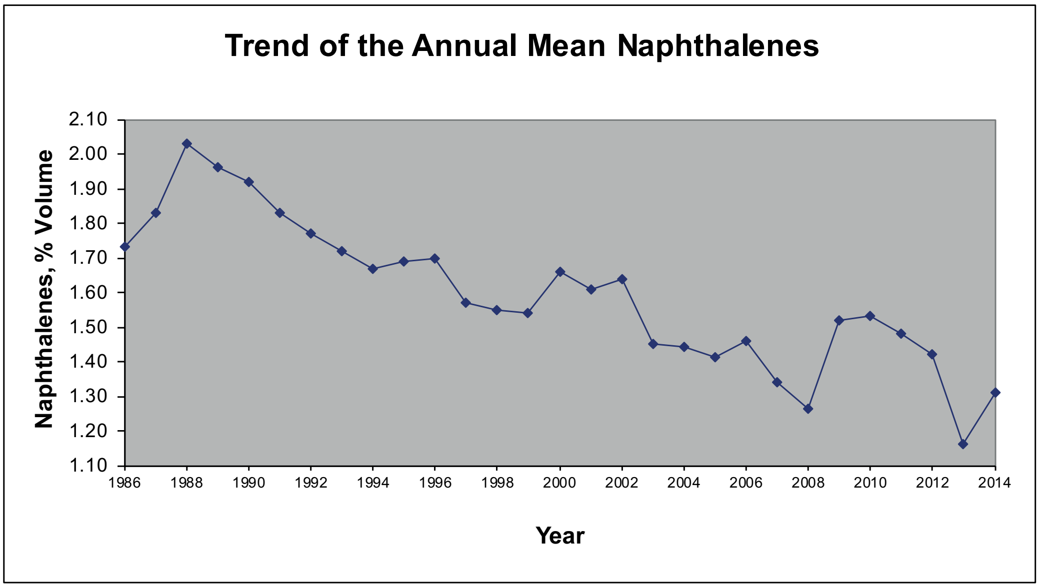

Figure B.34: Naphthalenes trend graph

B.18 EXISTENT GUM

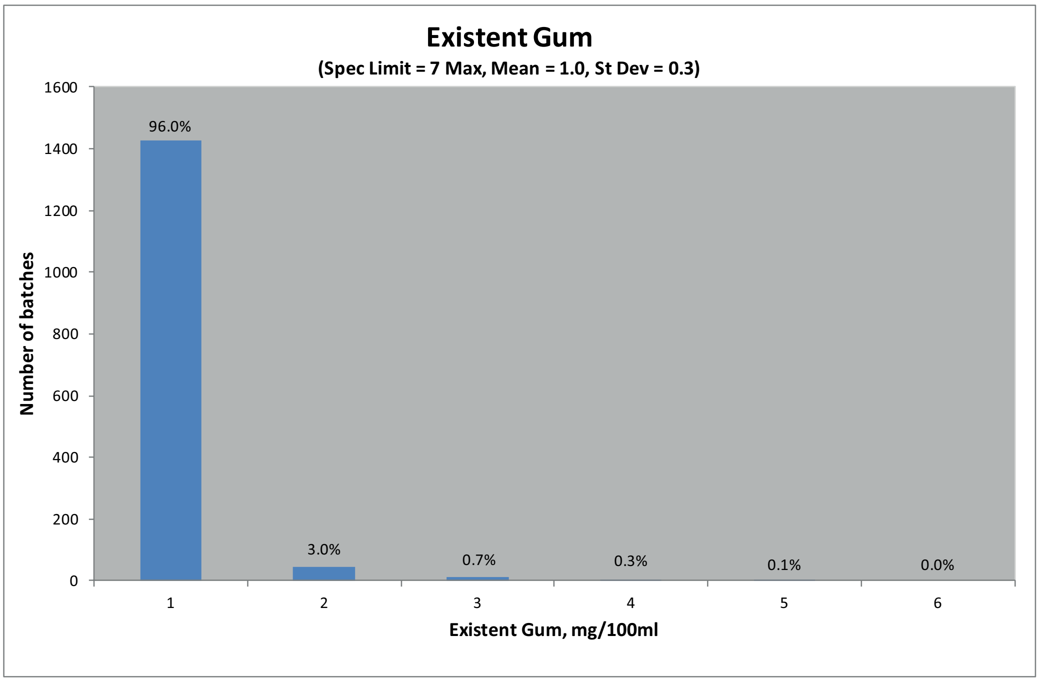

Figure B.35: Existent gum histogram

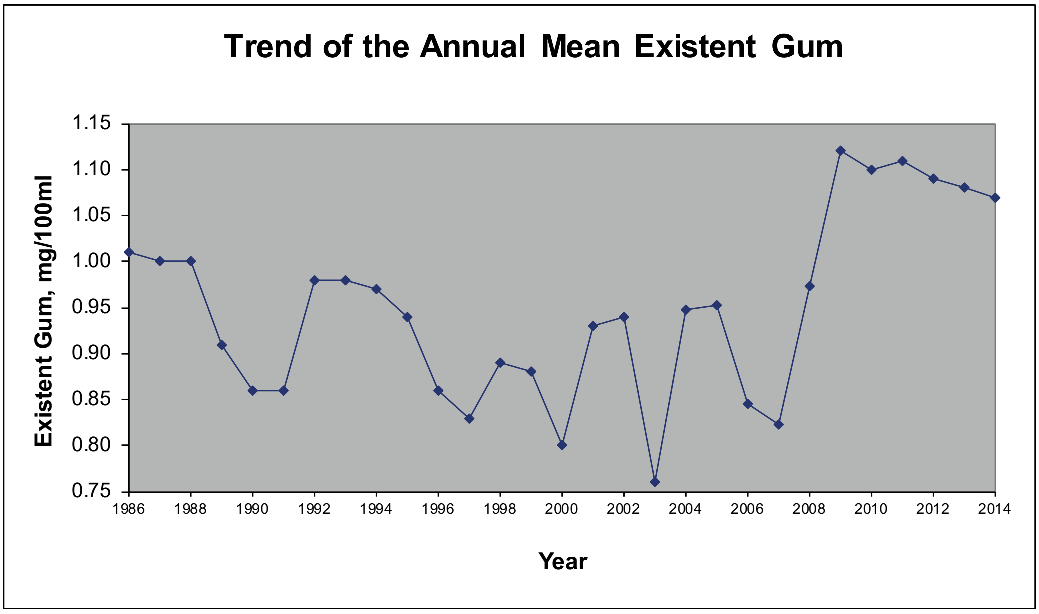

Figure B.36: Existent gum trend graph

B.19 MSEP®

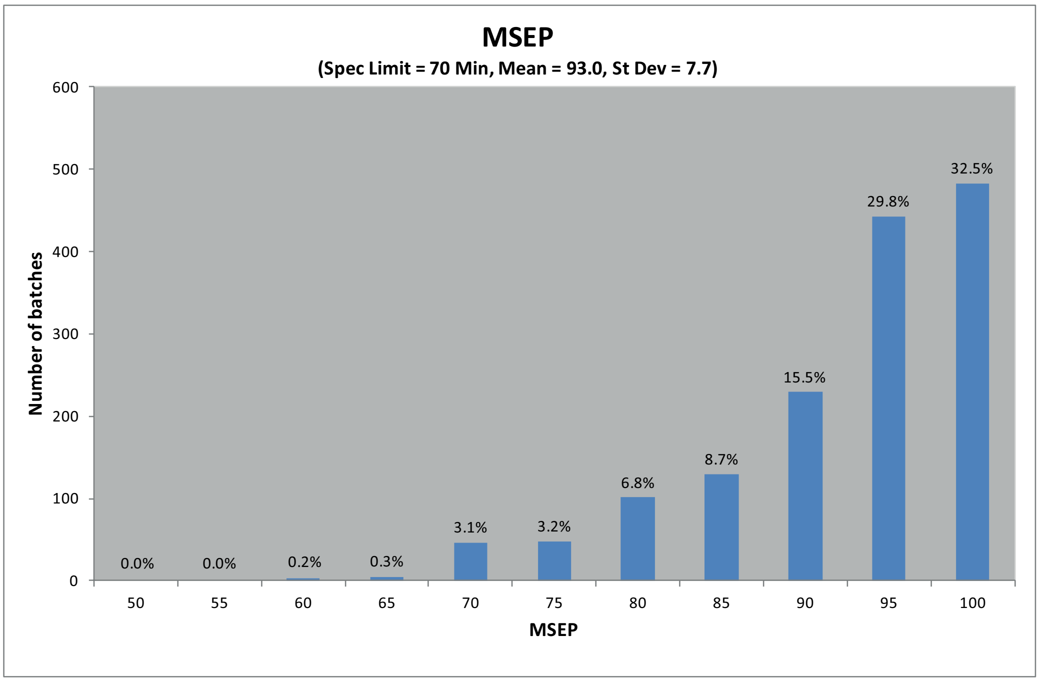

Figure B.37: MSEP® histogram

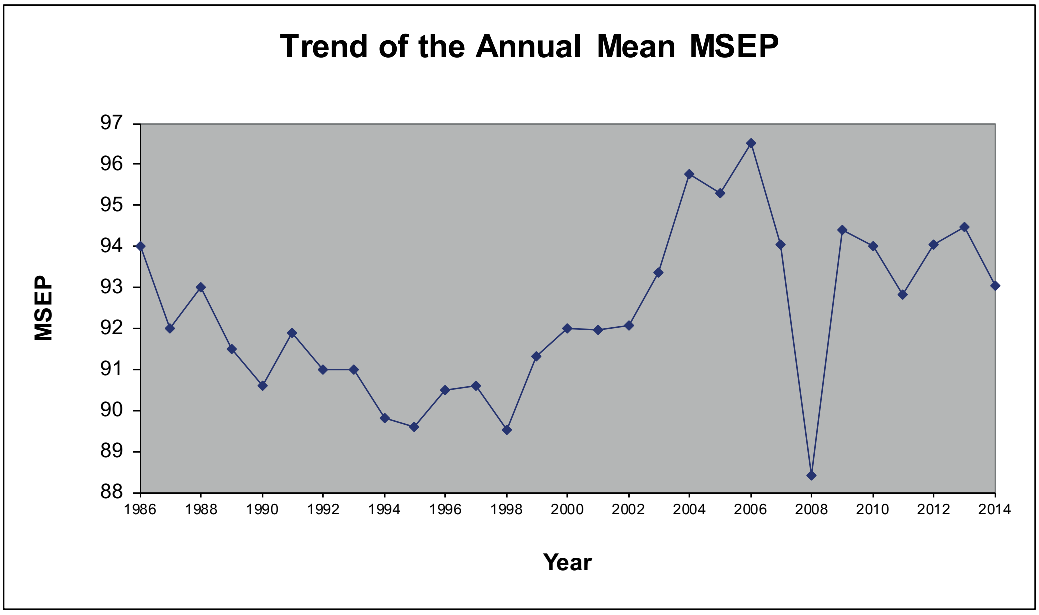

Figure B.38: MSEP® trend graph

B.20 PARTICULATE (GRAVIMETRIC)

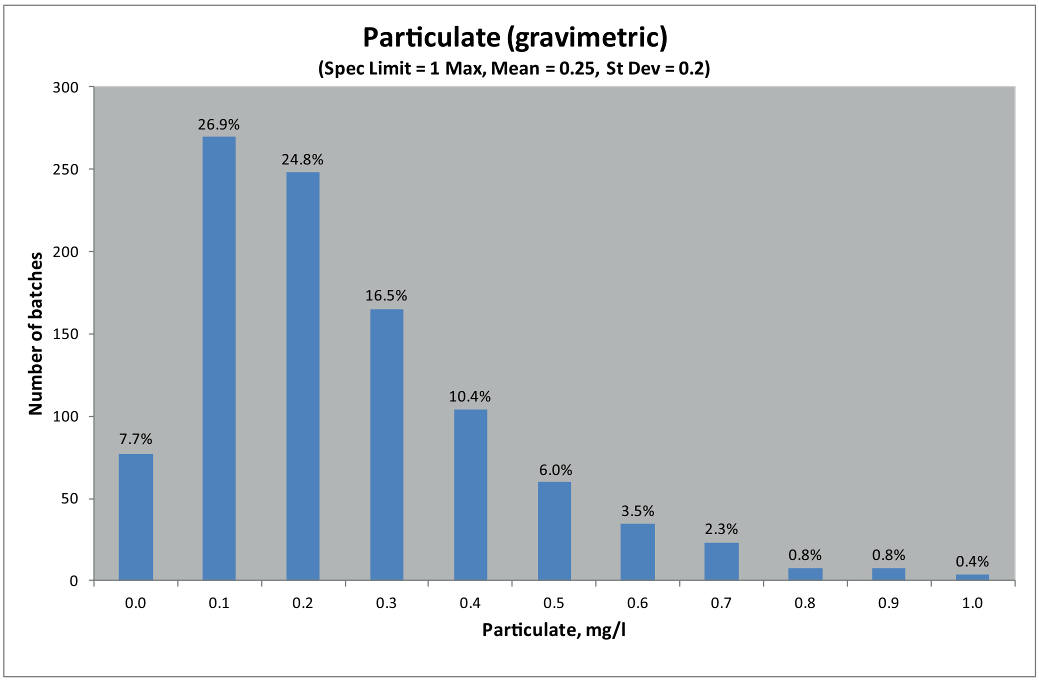

Figure B.39: Particulate histogram

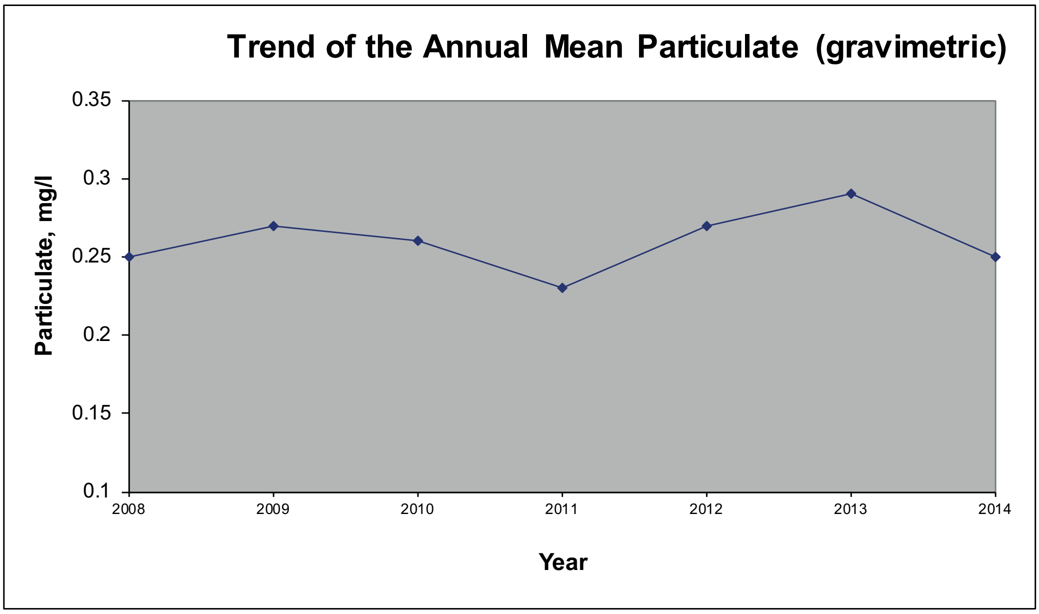

Figure B.40: Particulate trend graph

B.21 SAYBOLT COLOUR

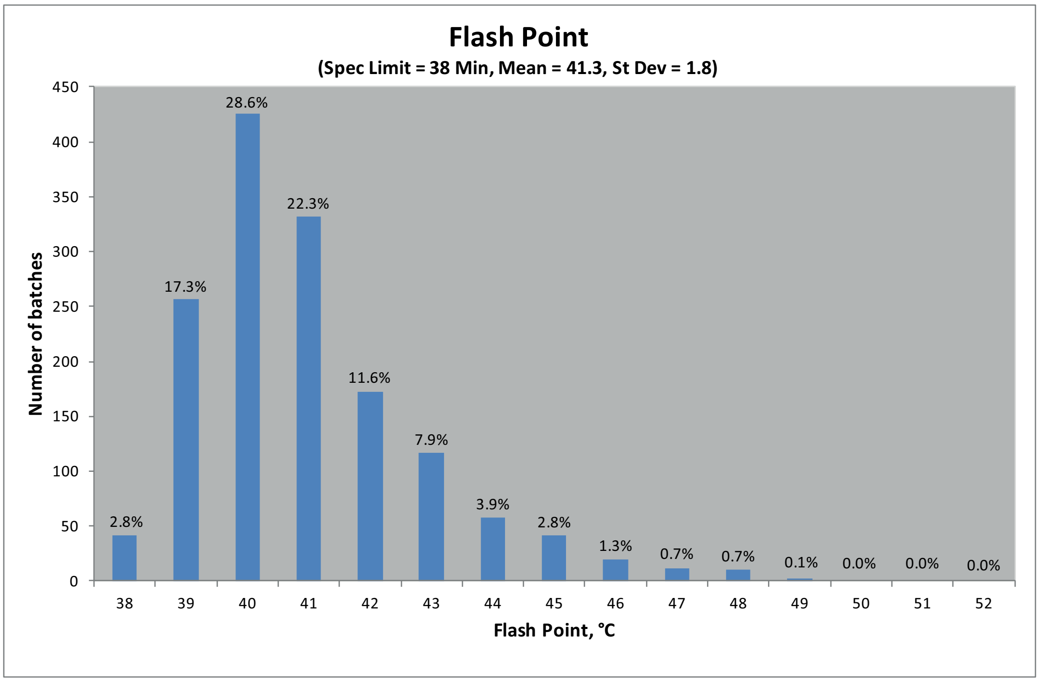

Figure B.41: Saybolt colour histogram

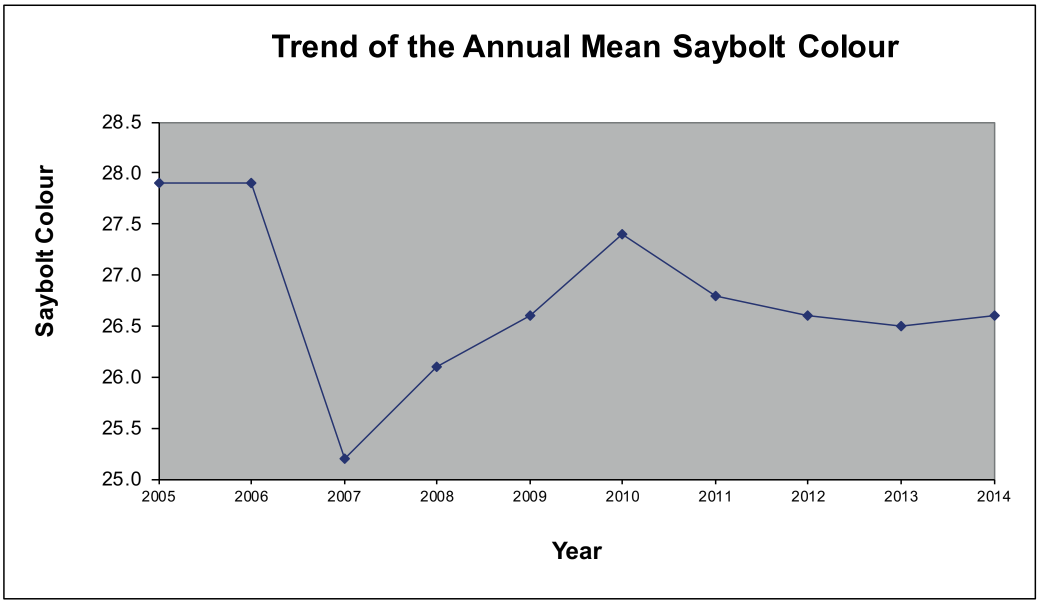

Figure B.42: Saybolt colour trend graph

B.22 PARTICLE COUNTS

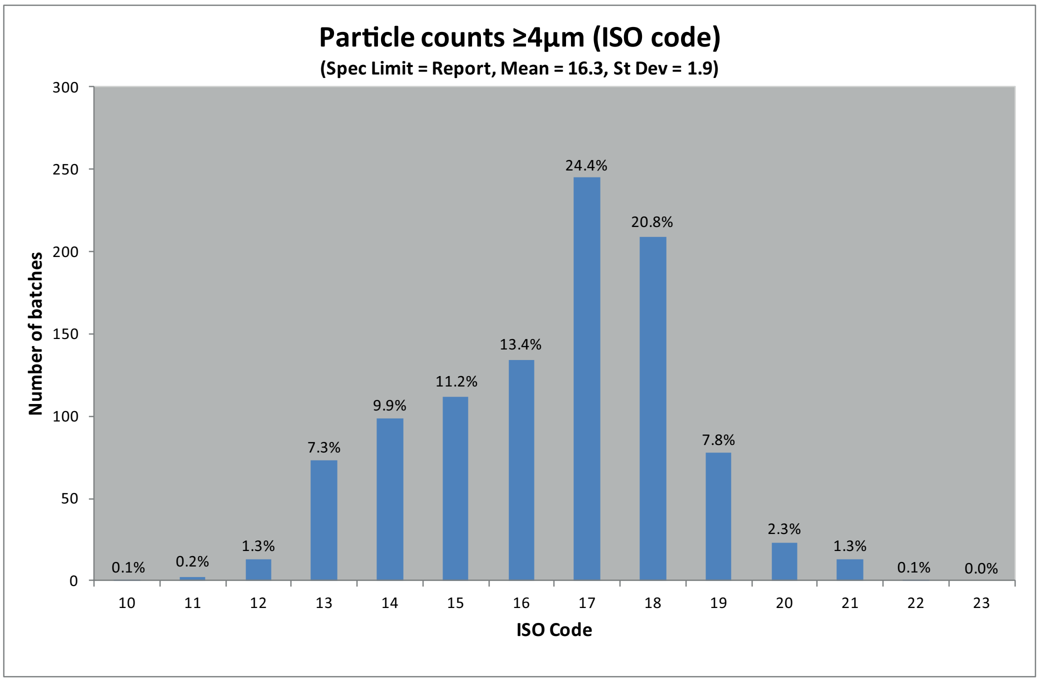

Figure B.43: Particle counts ≥4 µm ISO code

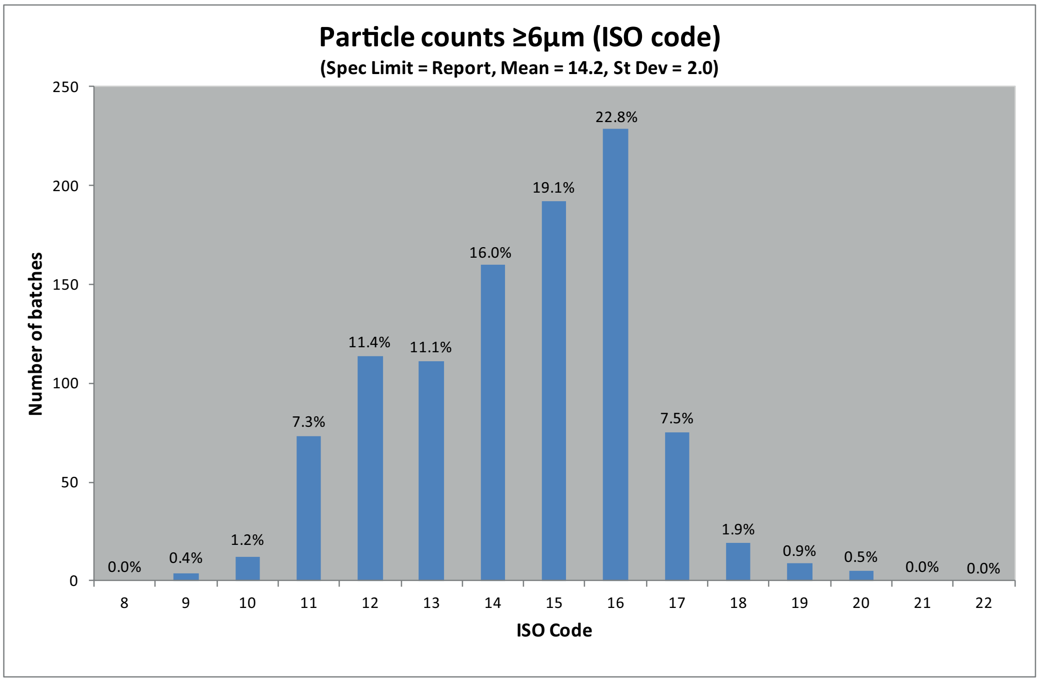

Figure B.44: Particle counts ≥6 µm ISO code

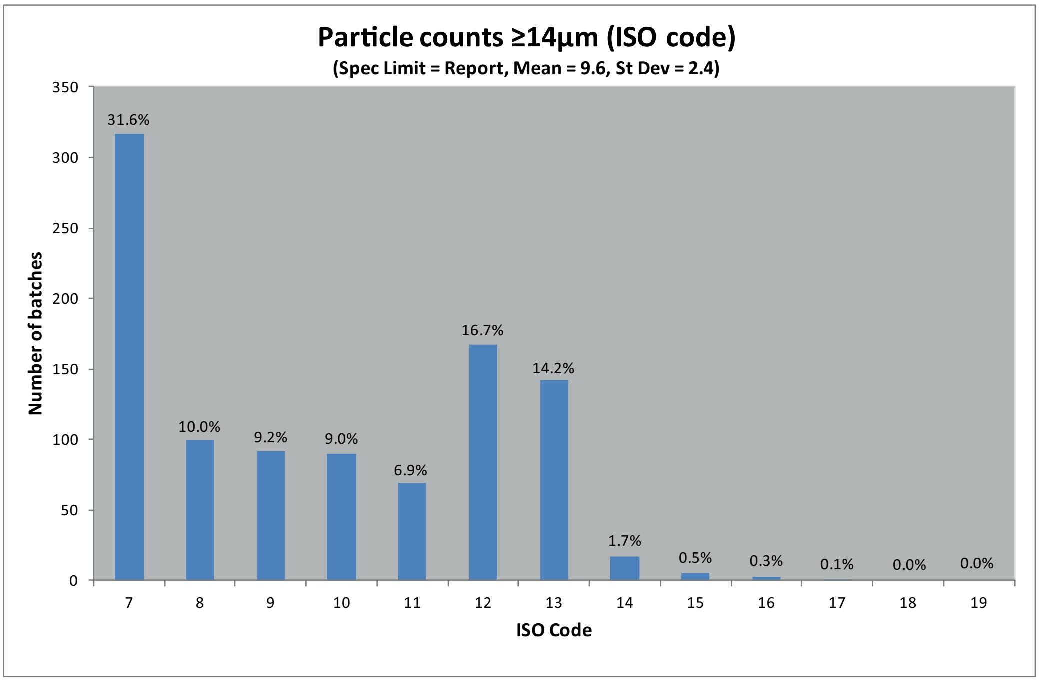

Figure B.45: Particle counts ≥14 µm ISO code

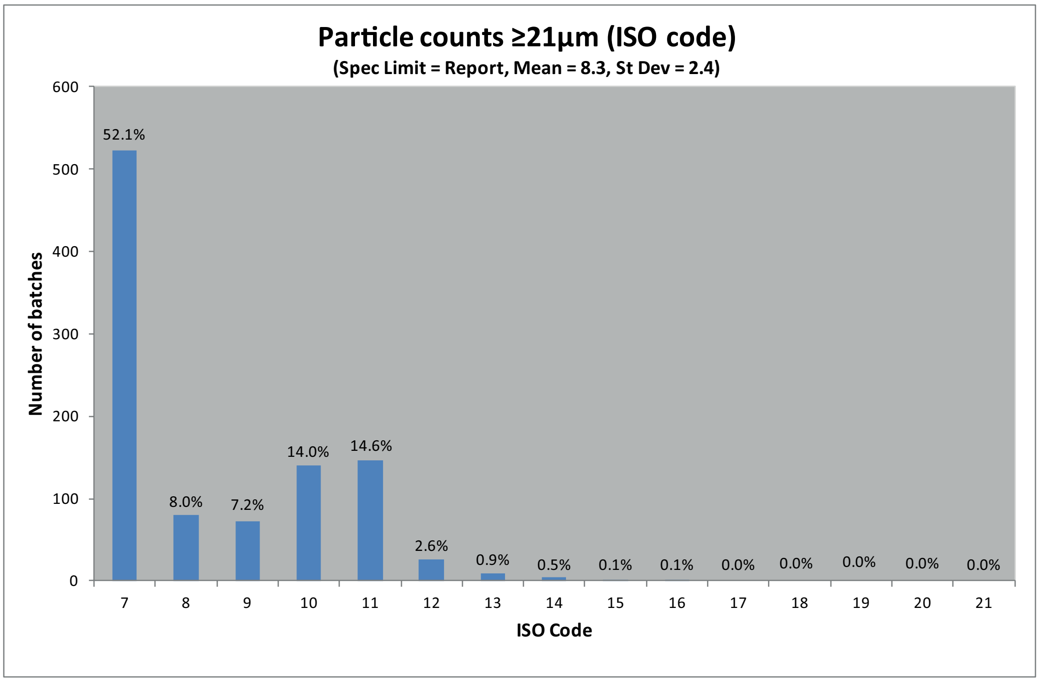

Figure B.46: Particle counts ≥21 µm ISO code

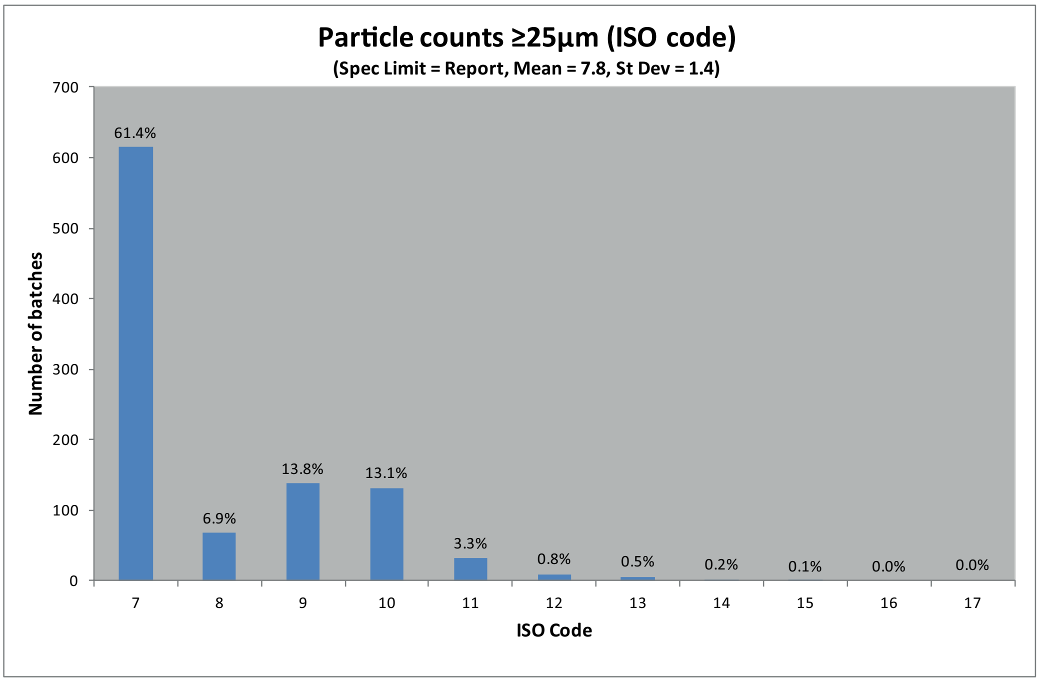

Figure B.47: Particle counts ≥25 µm ISO code

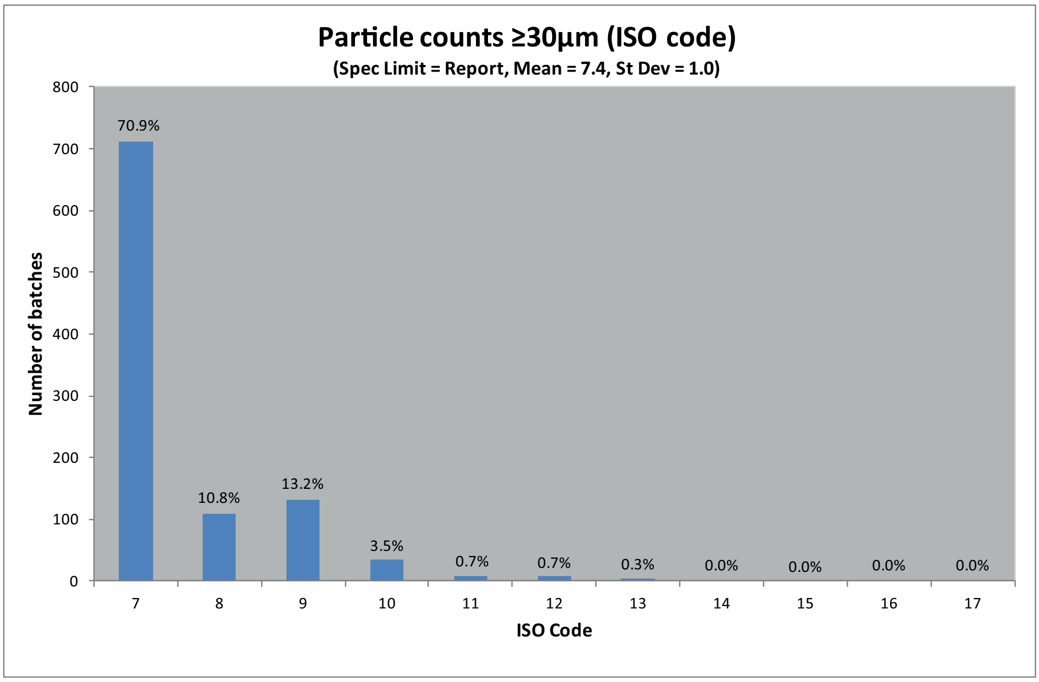

Figure B.48: Particle counts ≥30 µm ISO code

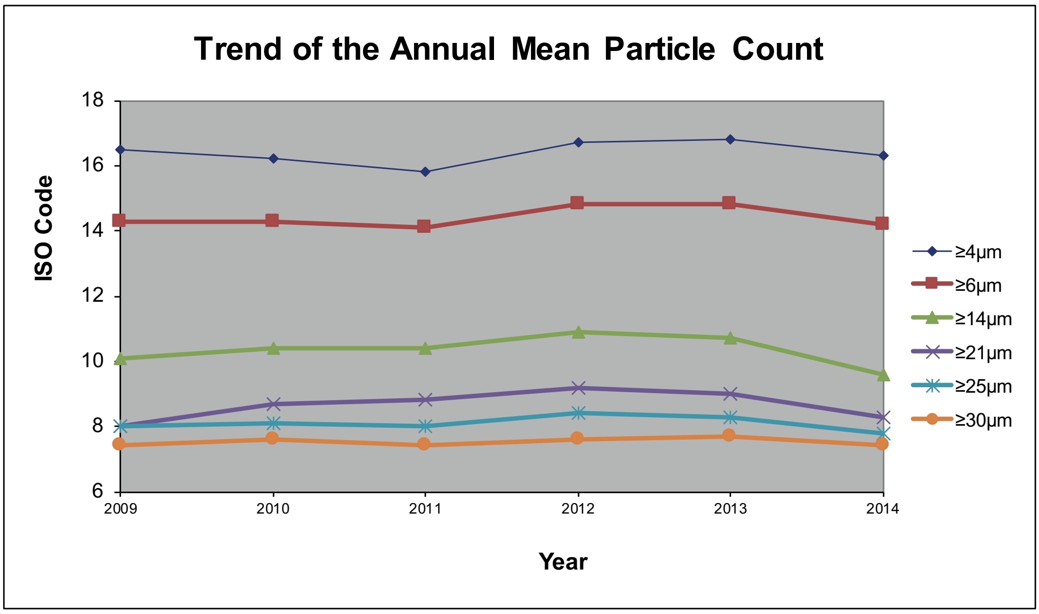

Figure B.49: Particle count trend graph

B.23 NEAR SPECIFICATION LIMIT TREND ANALYSIS

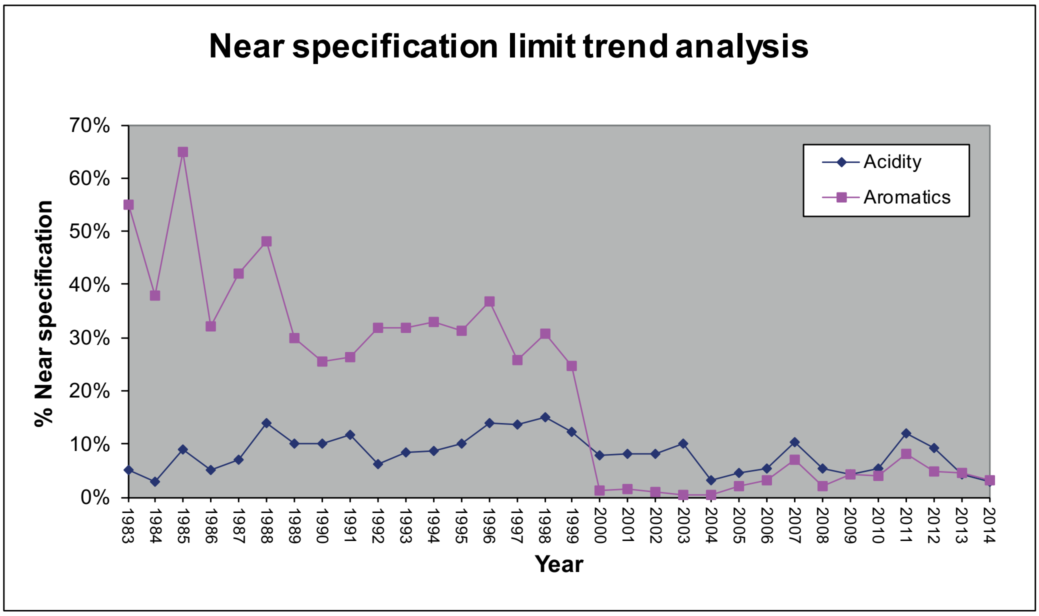

Figure B.50: Near specification trend, acidity and aromatics

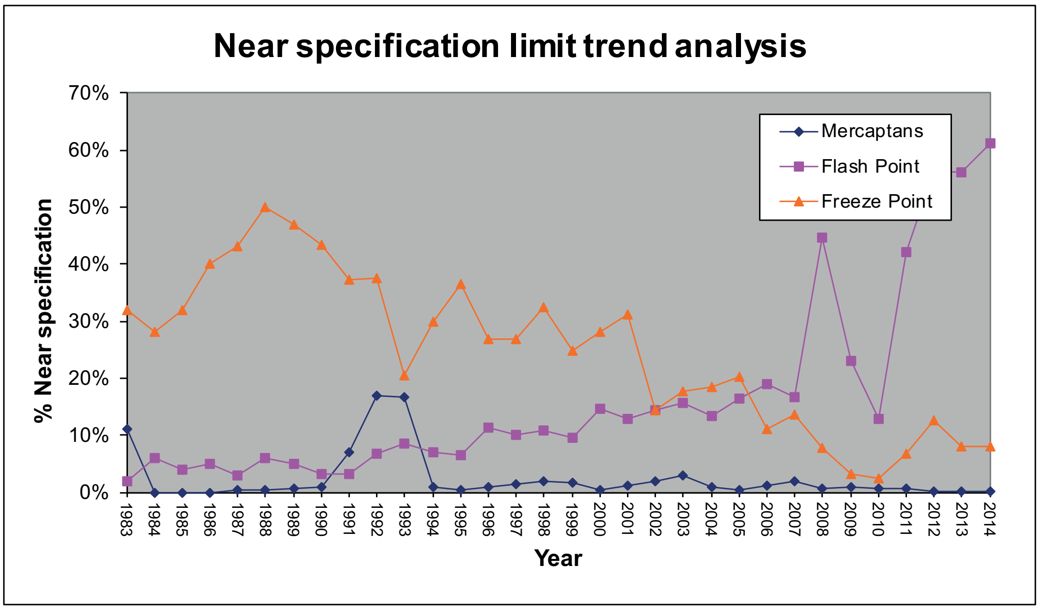

Figure B.51: Near specification trend, mercaptans, flash point and freezing point

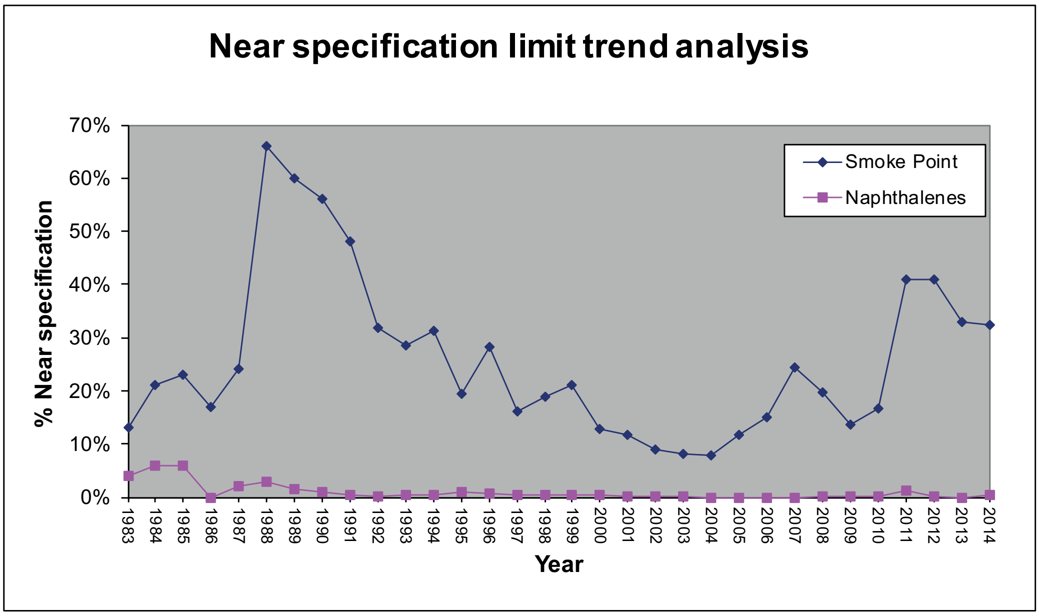

Figure B.52: Near specification trend, smoke point and naphthalenes

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