CRC/EI Research report

The quality of aviation fuel available in the United Kingdom

Annual survey 2016-2017

CRC project AV-18-19

CRC/EI RESEARCH REPORT

THE QUALITY OF AVIATION FUEL AVAILABLE IN THE UNITED KINGDOM
ANNUAL SURVEY 2016–2017

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CONTENTS

Contents continued

LIST OF FIGURES AND TABLES

Page

Figures

Tables

ABSTRACT

This report, jointly funded by the Coordinating Research Council (CRC) and the Energy Institute contains a summary of the data relating to the specification properties for AVTUR (Jet A-1) supplied in the United Kingdom during 2016 and 2017. The data for each year is expressed separately, in the form of histograms and mean values, which are graphically compared over the period 1986–2017. This report is the 39th in a series of survey reports.

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])[1–25]. This report covers a similar survey for aviation fuel (Jet A-1) supplied during the years 2016 and 2017, including 1 232 and 1 116 batches respectively complying with Defence Standard 91-091[26]. Historically, this survey was funded by the UK Ministry of Defence (MoD) in support of their specification development activities. In previous years the work was part-funded by the Energy Institute (EI). As the MoD ceased to fund the activity after the 2008 survey was produced, 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 batches of aviation fuel released during 2016 and 2017. The data has been expressed in the form of histograms and mean values, which are graphically compared over the period of 1986 to 2017. Due to the variation in volume of each fuel batch, the mean values are expressed as weighted means according to the relative fuel volume associated with each data point.

Historically most batches of aviation fuel used for this survey were refined in the UK. However, over time many UK refineries have closed resulting in more finished fuels being imported into the UK. Whilst the data provided does not give exact details on the number of imports, it is expected that a large proportion of the data contained in this survey is from imported batches. Therefore, the data presented is likely to be partly representative of aviation fuel available worldwide.

In this survey, the percentage of results near to the specification limits are reported for selected properties, which were chosen for historical reasons (to allow comparisons with previous years) and include some properties that appear to limit aviation 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.

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

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. The FLC then became part of QinetiQ and has been part of Intertek since 2011.

2 RESULTS

The data reported has been collated 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 2016 and 2017. The data for all but four of the properties detailed in Defence Standard 91-091 for AVTUR are summarised in tables and figures in the annexes. The data for copper corrosion and thermal stability were not included as most 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. No deposit thickness data was reported. All thermal stability results were reported at 260 °C. The data for electrical conductivity was also not included as at the point of testing, the conductivity of many batches was below the specification limits. This is permitted on the condition that Static Dissipater Additive (SDA) is added further downstream to ensure that the conductivity limits are met at the point of delivery into aircraft.[26]

2.1 TABULATED DATA

Tables A.1 and A.2 detail the specification limits for each property from Defence Standard 91-091 compared to the maxima and minima of the AVTUR data collected for the respective years.

2.2 HISTOGRAMS AND TREND GRAPHS FOR ANNUAL MEAN RESULTS

Figure B.1 to Figure B.80 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 weighted mean results for each property plotted against year for the period 1986 to 2017.

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.4) includes a range of results from >9 to ≤11.

2.3 GRAPHS OF NEAR SPECIFICATION TRENDS FOR AVTUR PRODUCED FROM 1986 TO 2017

For seven specification properties, Figure B.78 to Figure B.80 show the percentage of batches that have results near the specification limits, plotted against year for the period 1986 to 2015. The properties the figures relate to are listed below.

Figure B.78 – acidity, aromatics

Figure B.79 – mercaptan sulphur, flash point, freezing point

Figure B.80 – smoke point, naphthalenes

3 DISCUSSION

In this section significant changes and points of interest for the aviation industry are discussed, as well as providing some details on limitations of the data provided. As already discussed in section 2, the data for thermal stability, copper corrosion and electrical conductivity are not included.

For batches containing more than 95 % hydroprocessed material, of which at least 20 % is severely hydroprocessed, BOCLE results should be reported. However, it was not possible to determine whether a BOCLE test was required for many batches as details about the refining process were not supplied.[2]

No BOCLE results were reported for the batches used in this survey.

3.1 SAMPLE SIZE

In 2016, 1 232 batches were recorded compared to 1 116 batches recorded in 2017. These batches represent 13 552 107 m^3 and 12 285 955 m^3 respectively. In total, this report includes data from over 68 000 individual test results.

In some cases, the data in the tables and histograms for some properties have been derived from less than the total number of batches. This can be due to the specification, for various reasons, allowing waivers, or due to the data provided having a small number of results unavailable.

3.2 TOTAL ACIDITY

The volume weighted mean value in 2016 and 2017 was 0,006 and 0,004 mg KOH/g respectively. The 2016 result is the largest result ever recorded in this series of surveys (Figure B.3). The percentage of batches 'near specification limit' has showed some fluctuation; 2016 showed the highest value recorded but this returned to normal in 2017.

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

3.3 AROMATICS

The volume weighted mean value was 17,5 % v/v in 2016 (Figure B.4) and 18,2 % v/v in 2017 (Figure B.5). There appears to be no trend in mean values.

2 It should be noted that some of the data supplied for this survey was not in the form of test certificates, but supplied in spreadsheet format. Whilst electronic data does not provide all of the data found on main batch test certificates, it does not suggest that the original certificate did not contain the correct information and does not suggest that the fuel did not comply with the requirements of Defence Standard 91-091.

Aircraft operators may be concerned about the problems caused by different batches of fuel having large variations in aromatics. In 2016 and 2017, aromatic content ranged from 9,6 % v/v to 24,9 % v/v with more than 98 % 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. The percentage of batches 'near specification limit' increased to 7 % in 2017, but remains low compared to historical values.

3.4 TOTAL SULPHUR

The volume weighted mean value was 0,050 % m/m (Figure B.7) in 2016, and 0,044 % m/m (Figure B.8) in 2017. There appears to be no apparent trend in recent years. The total sulphur content also appears to show a multimodal distribution.

Defence Standard 91-091 allows several different methods for determining the sulphur content. Some laboratories use methods that can determine the sulphur content to three decimal places, whereas different methods or older equipment are only capable to report results to two decimal places. The most commonly used test method is IP 336, which is reportable to 0,01 % m/m (with a scope minimum of 0,03 % m/m)[27]. Consequently, results for many batches are reported to two decimal places and those with low sulphur contents have been reported as '<0,01 % m/m'. For the purposes for this survey, to remain consistent with previous publications, such results have been recorded without the 'less than' sign.

The use of different methods means that accurate data for the sulphur content in batches with low levels of sulphur is not possible, and this – alongside how the results are reported – may have an effect on the apparent weighted mean value.

3.5 MERCAPTAN SULPHUR

Mercaptan sulphur was reported for approximately half of batches as mercaptan sulphur is not required to be reported if the Doctor test is negative. The volume weighted mean was 0,0004 % m/m and 0,0006 % m/m in 2016 and 2017 respectively (Figures B.10 and B.11). The weighted mean values are lower than in previous years (Figure B.12).

Results for a number of batches showed the mercaptan sulphur content as '<0,001'. For the purposes of this survey, these results have been recorded as 0,001. As mentioned in 3.4, this may influence the weighted mean value. Furthermore, because many batches are not tested for mercaptan sulphur (where the doctor test is negative), the true mean value of mercaptan sulphur in jet fuel is likely to be lower than reported here.

3.6 DISTILLATION

The volume weighted mean value for Initial Boiling Point (IBP) was 148,0 °C in 2016 and 148,5 °C in 2017 (Figures B.13 and B.14). The mean values in 2016 and 2017 for 10 % recovered were both 165,9 °C (Figures B.16 and B.17). 50 % recovered results in 2016 and 2017 were 192,5 °C and 192,3 °C respectively (Figures B.19 and B.20).

IBP, 10 % and 50 % recovered values are slightly increased from the previous survey, however, they remain historically low. Distillation along with other properties, such as flash point, density, and viscosity have shown trends in the previous decade indicating jet fuel containing more volatile components. The latest survey suggests this trend may be levelling off, perhaps as some properties approach specification limits.

The 2016 and 2017 weighted mean values for 90 % recovered were 235,5 °C and 233,7 °C respectively (Figure B.22 and B.23). The Final Boiling Point (FBP) weighted means of 257,7 °C and 256,5 °C recorded in 2016 and 2017 (Figure B.25 and B.26) show no consistent trend (Figure B.27).

Aviation turbine fuels containing synthesized hydrocarbons, in accordance with ASTM D7566[28], have extended requirements (over ASTM D1655 and Defence Standard 91-091) to ensure a sufficient distillation range[3]. The requirements for T50-T10 are a minimum of 15 °C, and for T90-T10 is a minimum of 40 °C.[4]

Of the 1 232 batches in 2016, all would have met the T50-T10 and the T90-T10 requirements. Of the 1 116 batches in 2017, one would have failed the T50-T10 requirement and two would have failed the T90-T10 requirement (Figures B.28–B.31).

3.7 FLASH POINT

The volume weighted mean value for flash point was 41,2 °C in 2016 and 41,0 °C in 2017 (Figures B.32 and B.34). This property has shown a decreasing mean value for many years. This survey shows some indication of this decrease levelling off as it approaches the specification limit.

The 'near specification limit' analysis for flash point is shown in Figure B.79. In 2016 and 2017, the proportion of batches that were 'near specification limit' was 62 % and 70 % respectively. 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.79 are partially due to the change in reproducibility. Flash point appears to be a major restraining factor in jet fuel production for some refineries.

3.8 DENSITY

The volume weighted mean for density was 797,7 kg/m^3 in 2016 and 797,0 kg/m^3 in 2017 (Figures B.35 and B.36). These values continue the decreasing trend observed since 2010 (Figure B.37). The specification limits are 775 kg/m^3 to 840 kg/m^3.

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

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

3.9 FREEZING POINT

The volume weighted mean value for 2016 was –53,1 °C and in 2017 was –53,5 °C (Figures B.38 and B.39).

The percentage of batches 'near specification limit' during 2016 and 2017 was approximately 4 % (Figure B.40). Freezing point no longer appears to be the major restraining factor in jet fuel production it once was for some refineries.

3.10 KINEMATIC VISCOSITY

The volume weighted mean value in both 2016 and 2017 was 3,60 cSt (Figure B.41 and B.42). The reducing trend in mean viscosity since 2010 appears to show some levelling off (Figure B.43)

The specification limit is 8 cSt maximum at –20 °C. However, it should be noted that the industry has been considering more stringent requirements of 12 cSt at –40 °C to benefit Extended-range Twin-engine Operations Performance Standards, which is approximately equivalent to 5,5 cSt at –20 °C. For 2016 and 2017 there were no batches that exceeded 5,5 cSt, with the maximum result being 5,083 cSt.

3.11 SPECIFIC ENERGY

The volume weighted mean was 43,26 MJ/kg and 43,27 MJ/kg in 2016 and 2017 respectively. There appears to be a rising trend since 2009 (Figure B.46). 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 2016 and 2017 was 23,9 mm and 24,0 mm (Figures B.47 and B.48). The smoke point specification limit changed from 19 mm to 18 mm minimum at the start of 2017. The 2016 histogram shows an unusual distribution with regard to the high percentage of results at 25 mm, which may be linked to the specification requirement for the measurement of naphthalenes when the smoke point is less than 25 mm, this is less apparent in the 2017 histogram.

Since 2010, there has been an increasing trend develop in the volume weighted mean values, with the 2017 result being the highest since 2005 (Figure B.49). The change in near specification results is largely due to changes in method reproducibility and specification limit rather than a change in smoke point distribution.

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 2016 and 2017 was 1,60 % vol and 1,34 % vol (Figures B.50 and B.51). There appeared to be a downward trend from 1988 to 2014, but there is no obvious trend in the last few years (Figure B.52). 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 the majority 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 2016 and 2017 mean values were 0,95 and 0,89 mg/100 ml as shown in Figures B.53 and B.54. The precision for existent gum is very poor; it is likely that all batches contain virtually no gum and the range of results 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.

3.15 MICROSEPAROMETER®

The 2016 mean MSEP® value of 90,1, which is a small decrease compared to the previous few years (Figure B.56). The 2017 mean MSEP® has a similar value of 90,2 (Figure B.57).

The Defence Standard 91-091 limits for MSEP® rating are a minimum of 85 without SDA (static dissipator additive), or 70 with SDA due to the over sensitivity of the test method to SDA. Approximately 1 % of batches had results below 70. Where there were batches that reported MSEP® failures, it is likely that these were downstream from the manufacture of the fuel.

3.16 PARTICULATE CONTAMINATION

Defence Standard 91-091 has a maximum limit of 1 mg/l, and 67 batches in 2016 and 94 batches in 2017 had a result above this limit. The batches where the limit was exceeded are from sources who import fuel and it is assumed that this testing may have been carried out at point of manufacture but, during shipment, additional particulate became entrained in the cargos and identified on re-test. The data from these sources was supplied in electronic format and not from test certificates constraining further investigation. The x-axis scale in the distribution graphs (Figures B.59 and B.60) changes above 2 mg/l to show all results.

As many batches used for this survey were imported fuel, not all batches had associated particulate contamination results.

Since the start of recording this property, there has been a slight increasing trend in particulate content and the mean values for 2016 and 2017 further support this trend (Figure B.61).

3.17 SAYBOLT COLOUR

Saybolt colour is a relatively new requirement for Defence standard 91-091. The 2016 volume weighted mean value was 27,1 (Figure B.62) and is comparable to results in recent years (Figure B.64). The 2017 volume weighted mean value decreased to 26,8 (Figure B.63). For the purposes of this survey, results that were reported as '>30' were recorded as '30'.

3.18 PARTICLE COUNTS

For ease of producing histograms, ISO codes have been used to indicate particle numbers[5,29]. Histograms show the distribution of ISO codes for ≥4 µm, ≥6 µm, ≥14 µm, ≥21 µm, ≥25 µm, and ≥30 µm channels (Figures B.65–B.76). 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 are shown in Figure B.77 over the period of 2009 to 2017. The mean values show no particular trends. No specification limits for this property were set at the time of these analyses.

3.19 BOCLE

There were no BOCLE results reported in 2016 or 2017.

3.20 NEAR SPECIFICATION TRENDS

Figure B.78 to Figure B.80 are graphs showing the percentage of batches with test results near the specification limit, against each year, for seven specification properties.

The property with the highest percentage of batches with results near the specification limit in 2016 and 2017 was flash point (62 % and 70 %). Smoke point batches near specification limit reduce dramatically due to test method and specification limit changes. It should be noted that the relatively new precision for flash point (IP 170) has significant effects on the number of batches near specification limit as mentioned above.

5 According to ISO 4406, codes are applicable to the ≥4 µm, ≥6 µm, and ≥14 µm channels. However, for the purposes of Defence Standard 91-091, codes are reported using the same ISO 4406 coding table, for all six channels.

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)
Particulate content (increasing since 2011)	Distillation 10 % recovery (decreasing since 1991)
Smoke point (increasing since 2010)	Distillation 50 % recovery (decreasing since 2010)
Specific energy (increasing since 2010)	Flash point (decreasing since 1991)
	Freezing point batches near specification limit (decreasing since 1988)
	Viscosity (decreasing since 1991)
	Density (decreasing since 2007)

4.2 SIGNIFICANT CHANGES

Table 2: Significant changes in mean values

Property	Change
Mercaptan sulphur	2016 and 2017 are the lowest mean value since records began in 1986.
Flash point	Highest value near to specification limit since records began.
Specific energy	Increase of 0,03 MJ/kg from 2015 to 2017.
Density	Dropped 2,3 kg/m^3 from 2015 to 2017 to the lowest value recorded.

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ANNEX A
RESULTS SUMMARIES

A.1 2016 – DATA FROM 1 232 BATCHES OF JET FUEL REPRESENTING 13 552 107 M³

Table A.1: Minima and maxima for 2016 data and specification limits

Method	Def Stan 91-091 specification limits		Results summary 2016		
	Min	Max	Min	Max	Mean
Total acidity, mg KOH/g	–	0,015	0,000	0,015	0,006
Aromatics, % volume	–	25,0[6]	11,2	24,2	17,5
Total sulphur, % mass	–	0,30	0,000	0,260	0,050
Mercaptan sulphur, % mass	–	0,0030	0,0000	0,0030	0,0004
Distillation IBP, °C	Report		137,4	171,8	148,0
10 % recovery, °C	–	205,0	146,8	189,0	166,7
50 % recovery, °C	Report		183,3	209,8	192,5
90 % recovery, °C	Report		218,8	255,5	235,5
FBP, °C	–	300,0	234,9	285,6	257,0
Flash point, °C	38,0	–	38,0	55,0	41,2
Density @ 15 °C, kg/m³	775,0	840,0	784,6	817,4	797,7
Freezing point, °C	–	–47,0	–62,9	–47,3	–53,1
Viscosity @ –20 °C, mm²/s	–	8,00	2,61	5,08	3,60
Specific energy, net MJ/kg	42,80	–	43,00	43,54	43,26
Smoke point, mm	19,0	–	19,1	27,0	23,7
Naphthalenes, % volume	–	3,00	0,02	2,96	1,60
Existent gum, mg/100 ml	–	7	0	5	0,95
MSEP®	85 (70 with SDA)	–	46	100	91
BOCLE, mm	–	0,85	N/A	N/A	N/A
Particulate, mg/l	–	1,0	0,01	5,10	0,34
Colour	Report		14	30	26,9
Particle count,					
≥4 µm	Report		11	23	16,3
≥6 µm	Report		9	23	14,4
≥14 µm	Report		7	17	10,4
≥21 µm	Report		7	14	8,9
≥25 µm	Report		7	13	8,3
≥30 µm	Report		7	13	7,8

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

A.2 2017 DATA FROM 1 116 BATCHES OF JET FUEL REPRESENTING 12 285 955 M^3

Table A.2: Minima and maxima for 2017 data and specification limits

Method	Def Stan 91-091 specification limits		Results summary 2017		
	Min	**Max**	**Min**	**Max**	**Mean**
Total acidity, mg KOH/g	–	0,015	0,000	0,015	0,004
Aromatics, % volume	–	25,0[7]	9,6	24,9	18,2
Total sulphur, % mass	–	0,30	0,000	0,207	0,044
Mercaptan sulphur, % mass	–	0,0030	0,0000	0,0030	0,0006
Distillation IBP, °C	Report		135,6	165,3	148,5
10 % recovery, °C	–	205,0	144,3	180,9	165,9
50 % recovery, °C	Report		177,0	204,9	192,3
90 % recovery, °C	Report		192,3	258,1	233,7
FBP, °C	–	300,0	223,1	288,5	256,5
Flash point, °C	38,0	–	38,0	48,0	41,0
Density @ 15 °C, kg/m^3	775,0	840,0	784,3	818,8	797,0
Freezing point, °C	–	–47,0	–70,3	–40,7	–53,4
Viscosity @ –20 °C, mm^2/s	–	8,00	2,91	4,44	3,56
Specific energy, Net MJ/kg	42,80	–	42,99	43,57	43,27
Smoke point, mm	18,0	–	18,0	30,3	24,0
Naphthalenes, % volume	–	3,00	0,05	2,99	1,34
Existent gum, mg/100 ml	–	7	0	7	0,89
MSEP®	85 (70 with SDA)	–	53	100	90
BOCLE, mm	–	0,85	N/A	N/A	N/A
Particulate, mg/l	–	1,0	0,00	4,80	0,34
Colour	Report		7	30	26,3
Particle count,					
≥4 µm	Report		12	22	15,7
≥6 µm	Report		10	21	13,8
≥14 µm	Report		7	16	9,6
≥21 µm	Report		7	14	8,1
≥25 µm	Report		7	14	7,7
≥30 µm	Report		7	14	7,5

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

ANNEX B
FIGURES

B.1 TOTAL ACIDITY

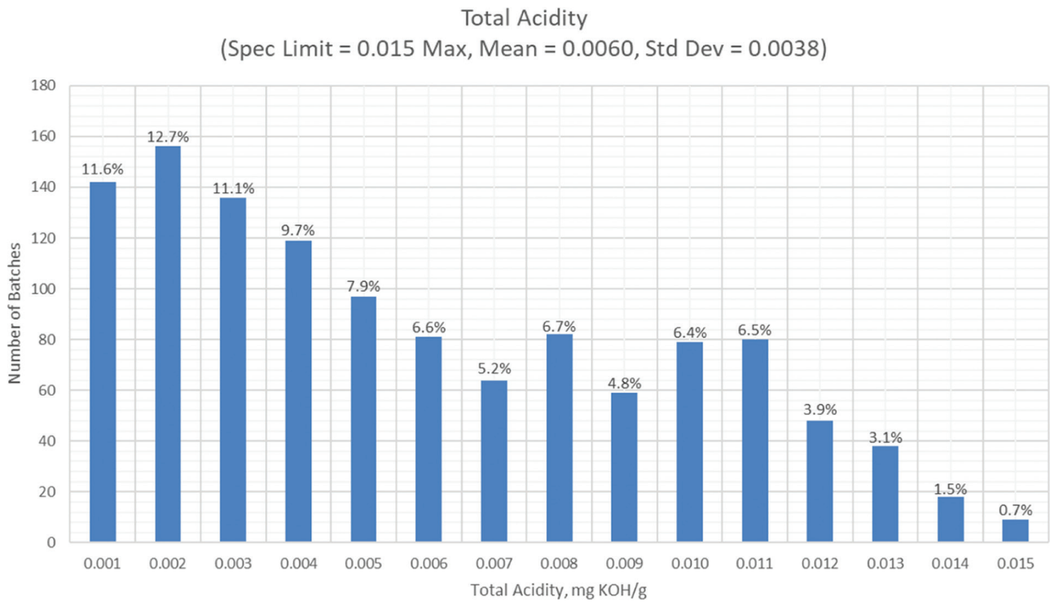

Figure B.1: Total acidity histogram (2016)

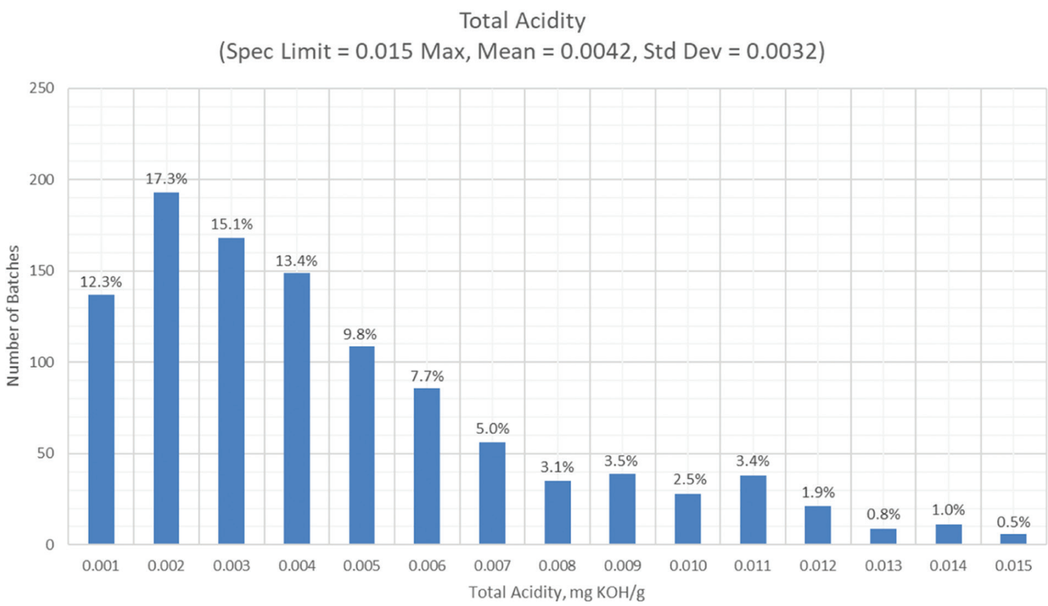

Figure B.2: Total acidity histogram (2017)

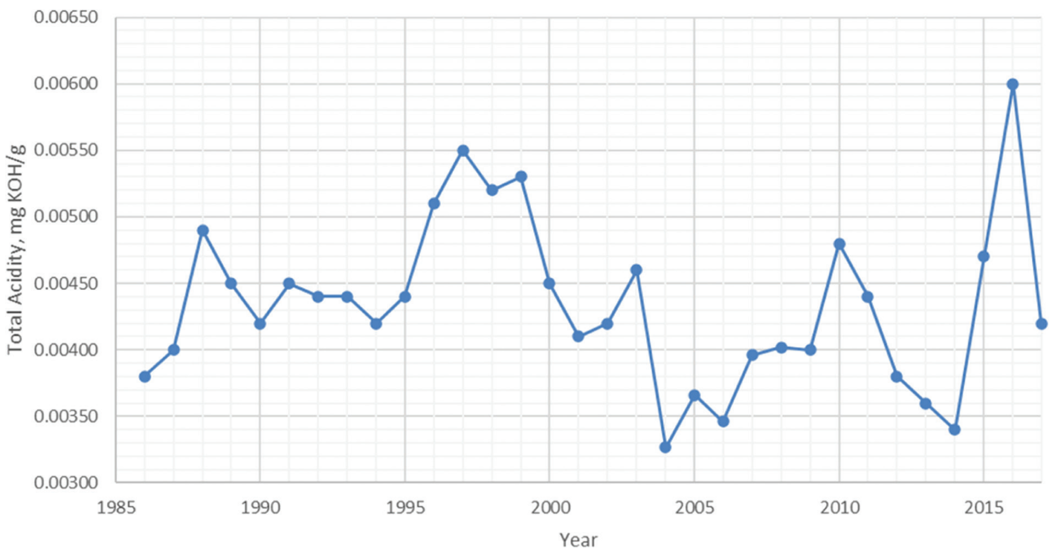

Figure B.3: Total acidity trend of the annual mean graph

B.2 AROMATICS

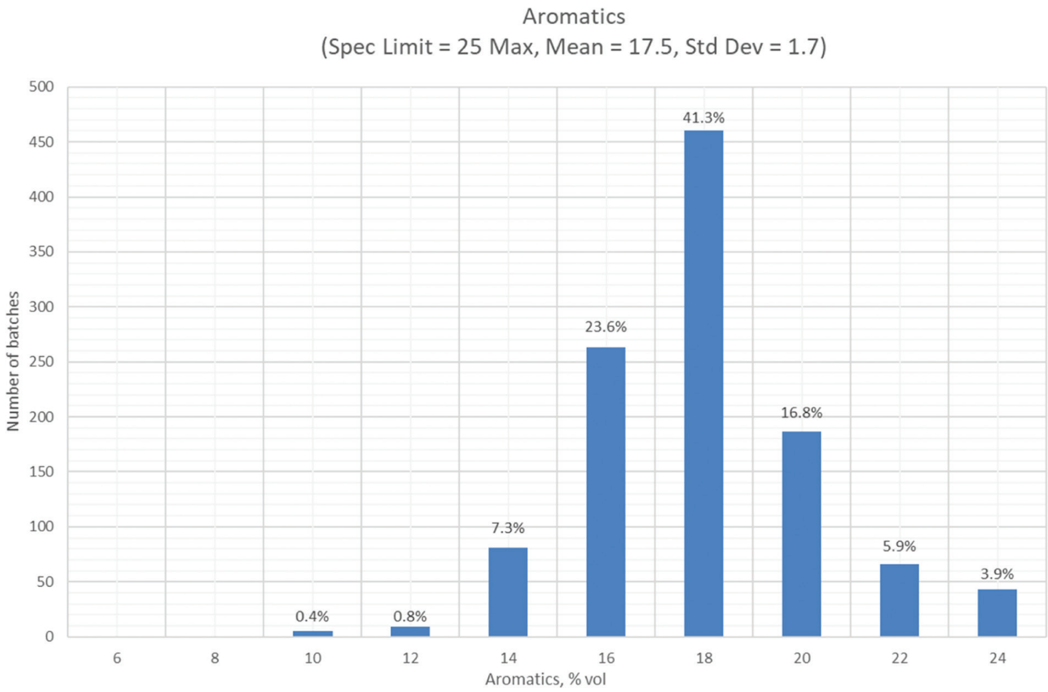

Figure B.4: Aromatics histogram (2016)

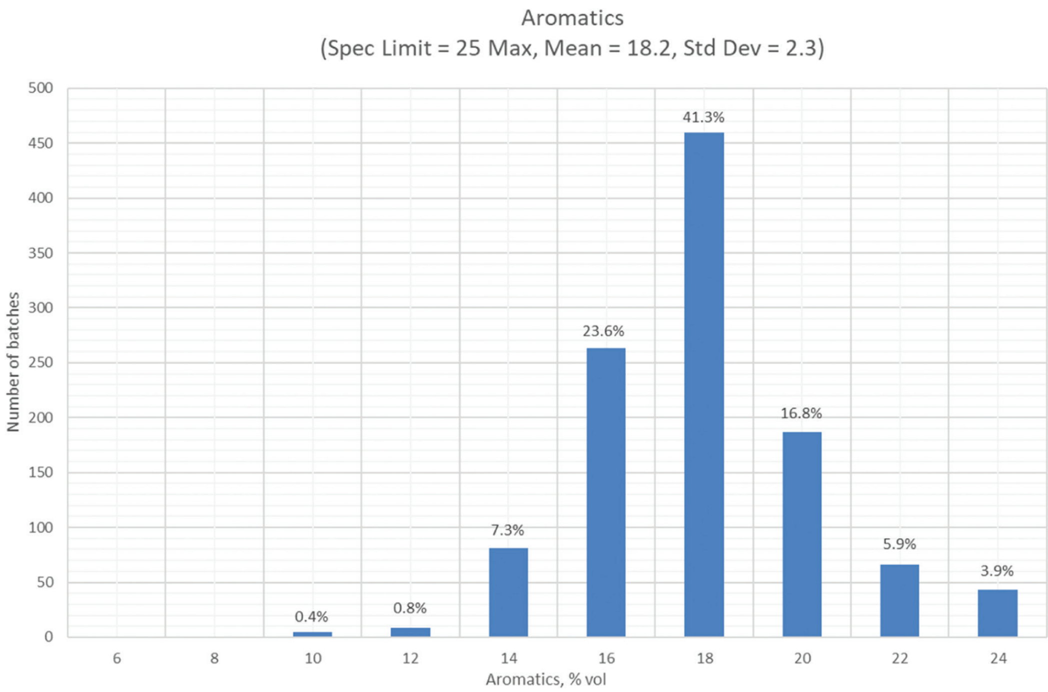

Figure B.5: Aromatics histogram (2017)

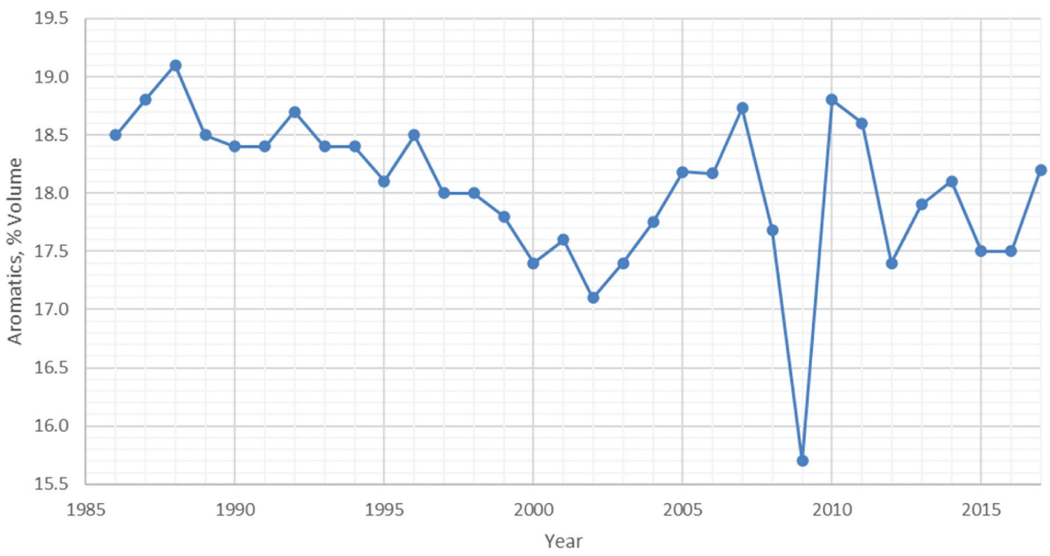

Figure B.6: Aromatics trend of the annual mean graph

B.3 TOTAL SULPHUR

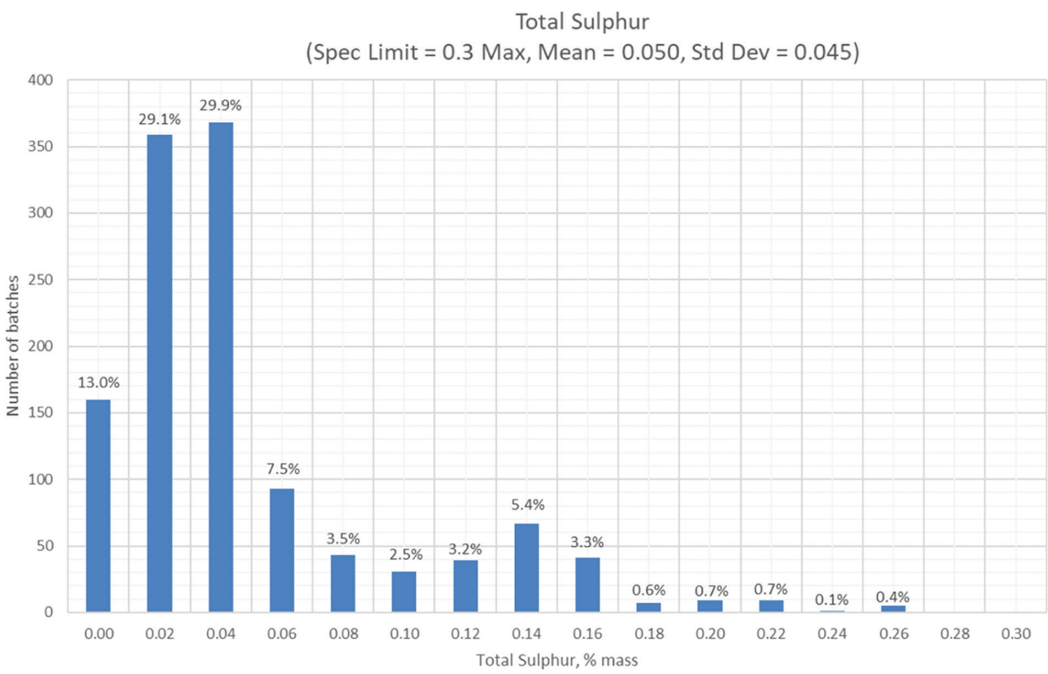

Figure B.7: Total sulphur histogram (2016)

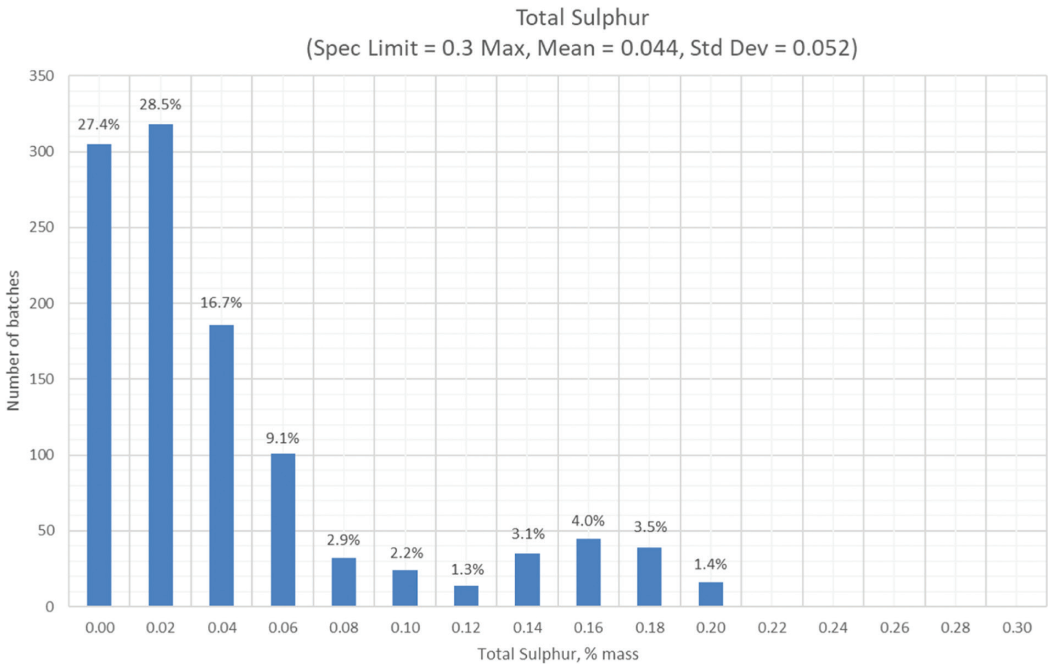

Figure B.8: Total sulphur histogram (2017)

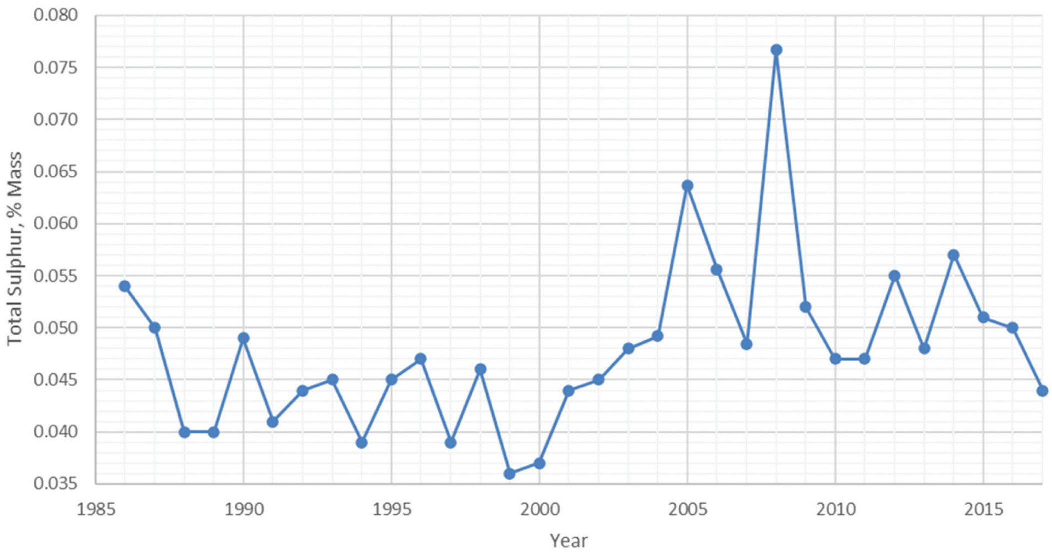

Figure B.9: Total sulphur trend of the annual mean graph

B.4 MERCAPTAN SULPHUR

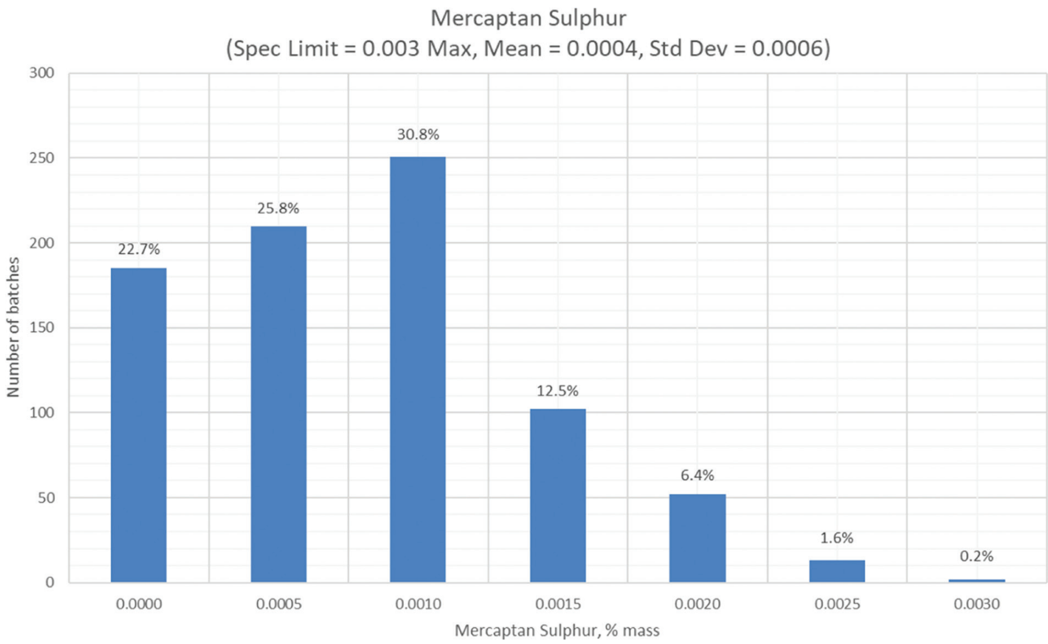

Figure B.10: Mercaptan sulphur histogram (2016)

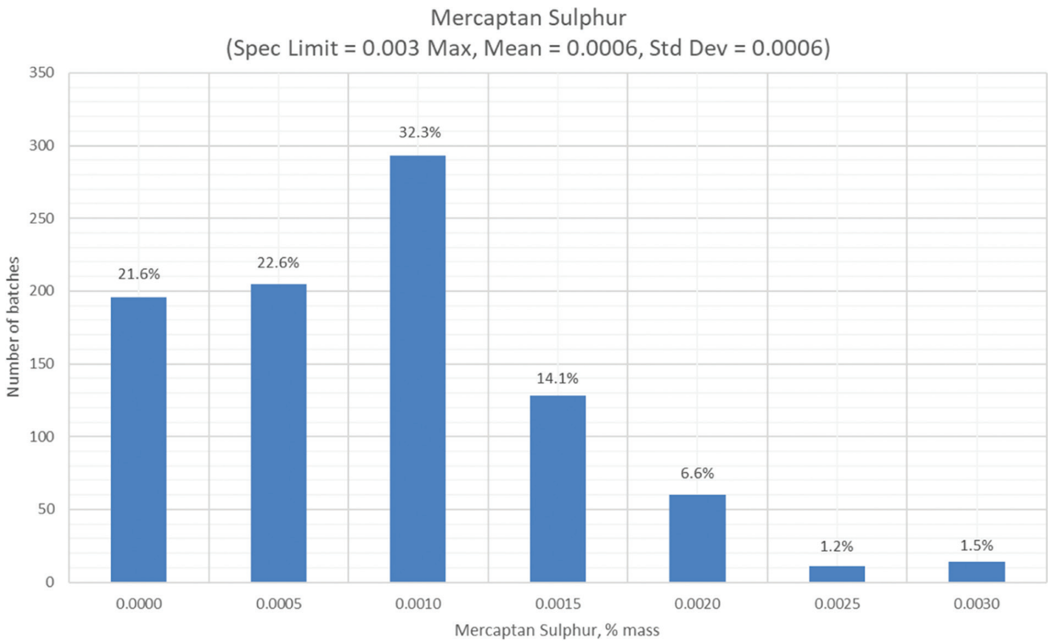

Figure B.11: Mercaptan sulphur histogram (2017)

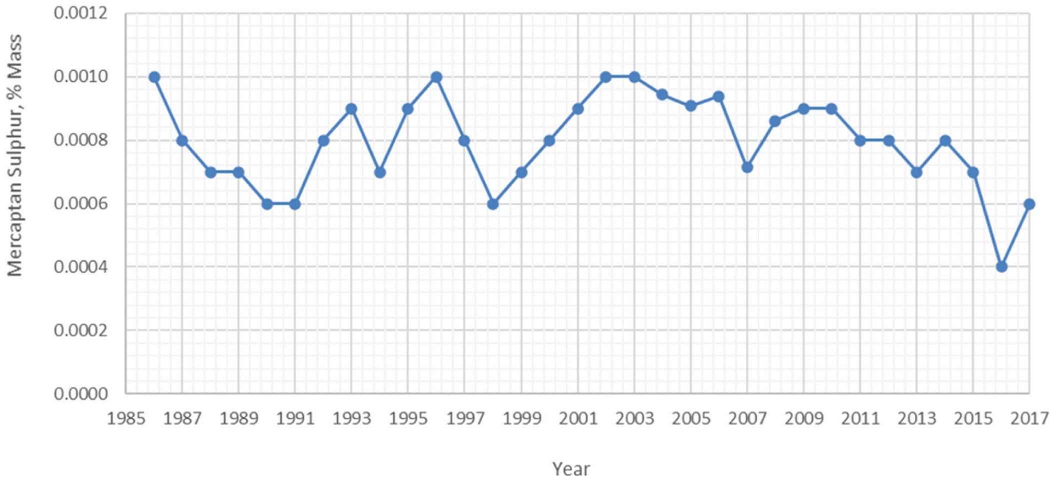

Figure B.12: Mercaptan trend of the annual mean graph

B.5 DISTILLATION IBP

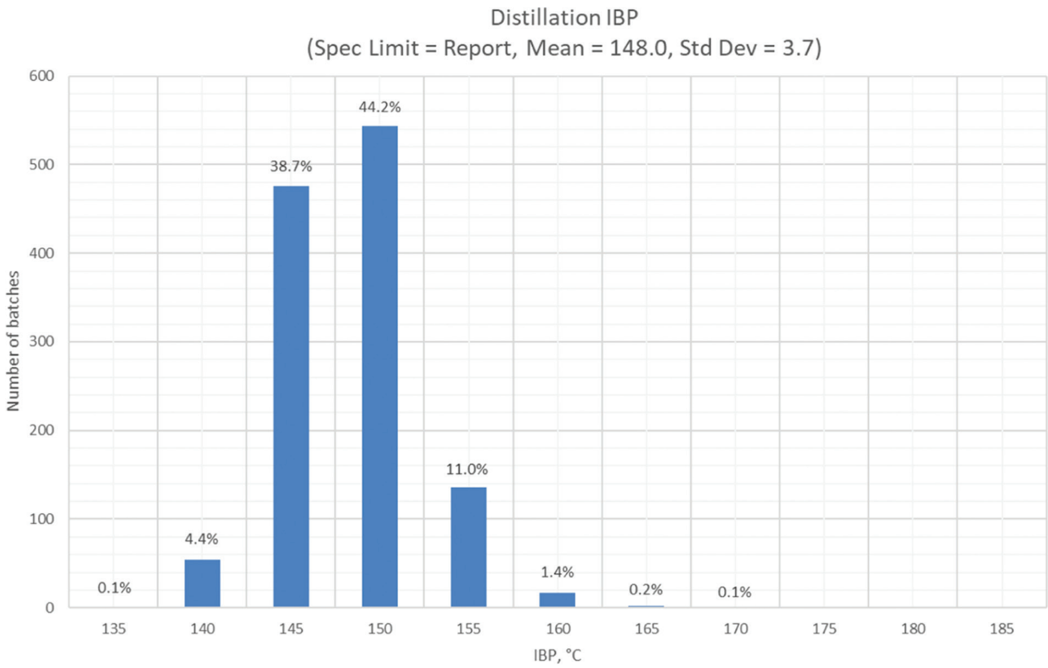

Figure B.13: Distillation IBP histogram (2016)

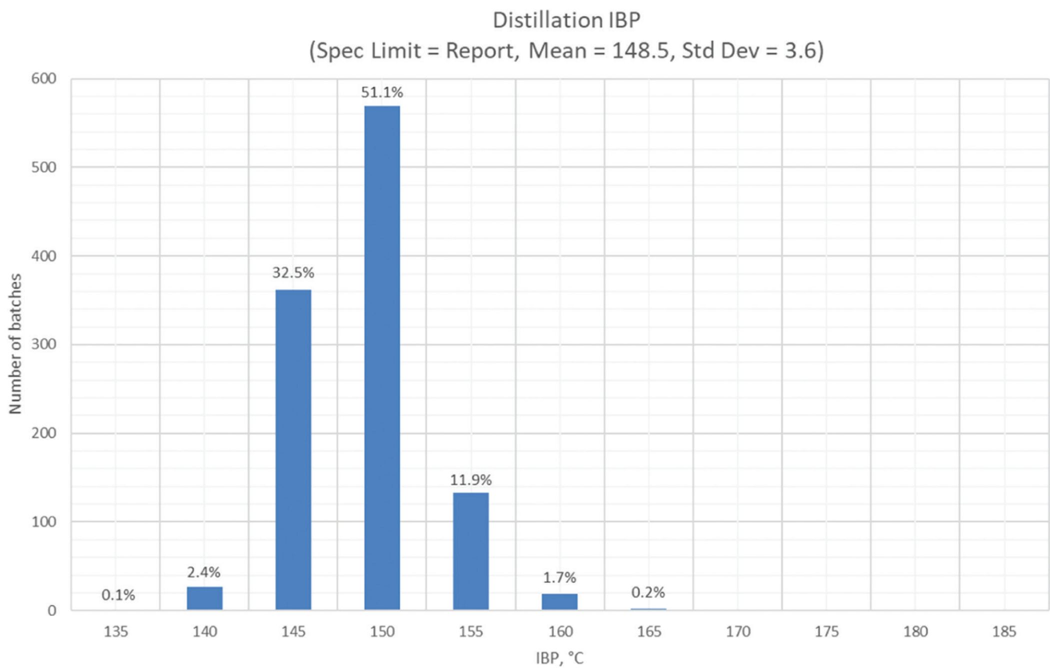

Figure B.14: Distillation IBP histogram (2017)

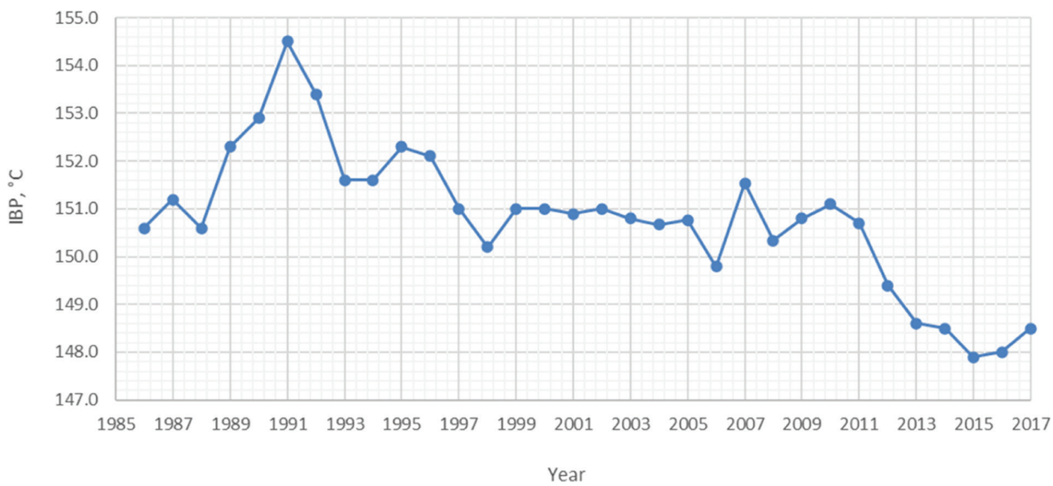

Figure B.15: Distillation IBP trend of the annual mean graph

B.6 DISTILLATION 10 % RECOVERY

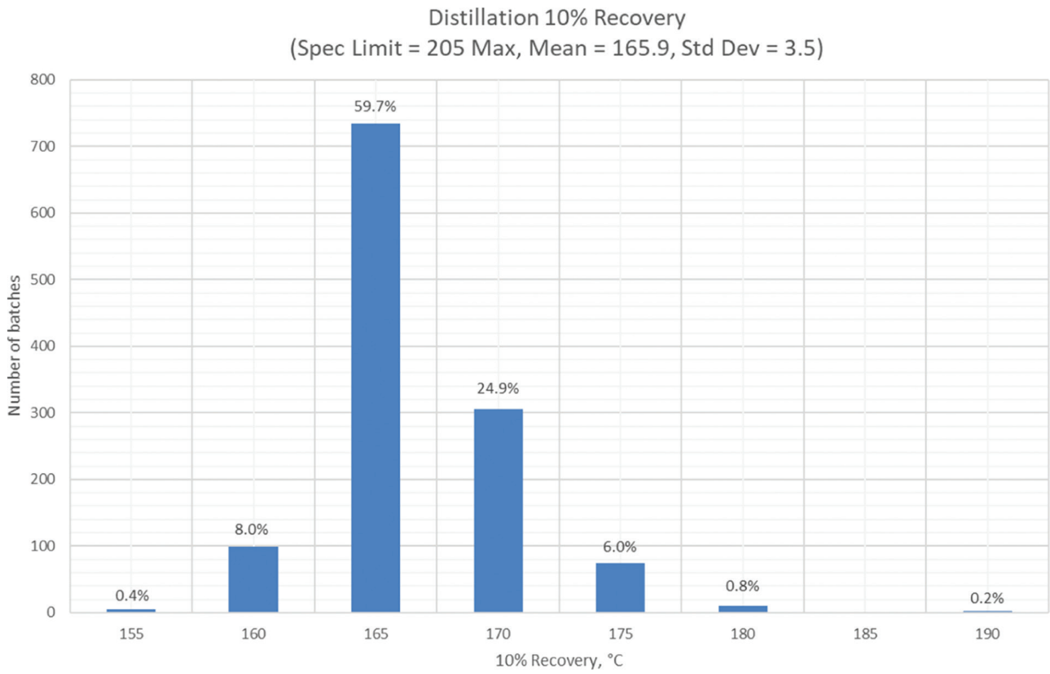

Figure B.16: Distillation 10 % recovery histogram (2016)

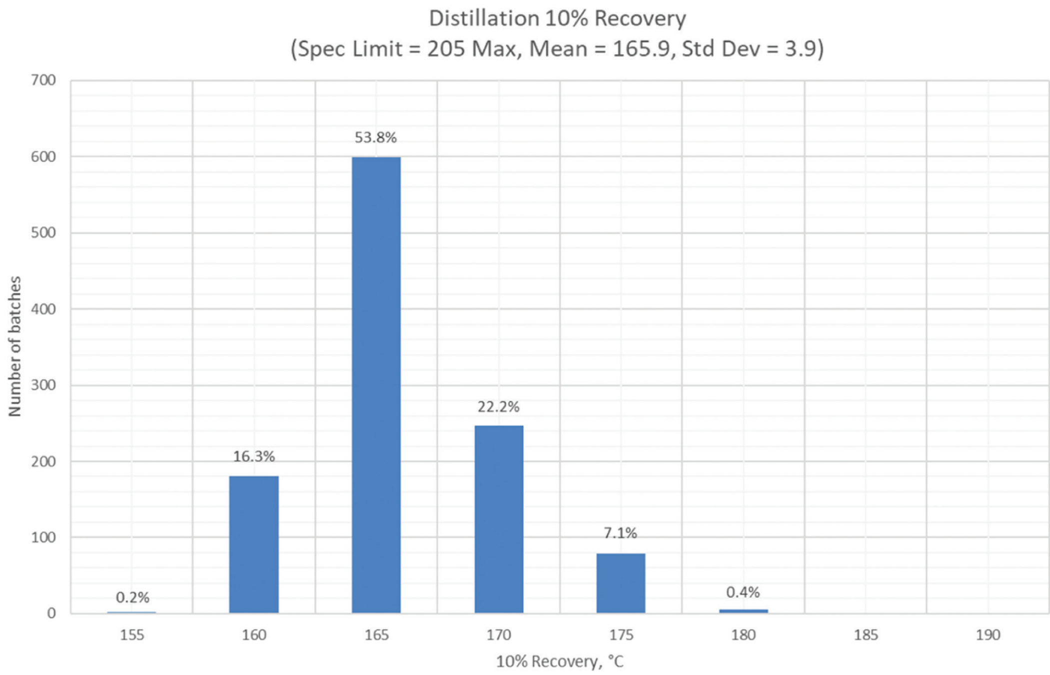

Figure B.17: Distillation 10 % recovery histogram (2017)

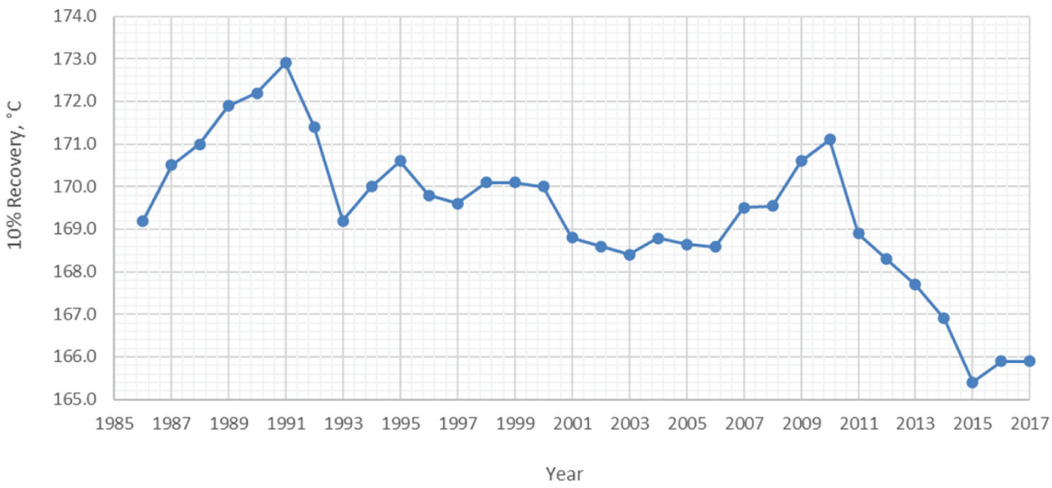

Figure B.18: Distillation 10 % recovery trend of the annual mean graph

B.7 DISTILLATION 50 % RECOVERY

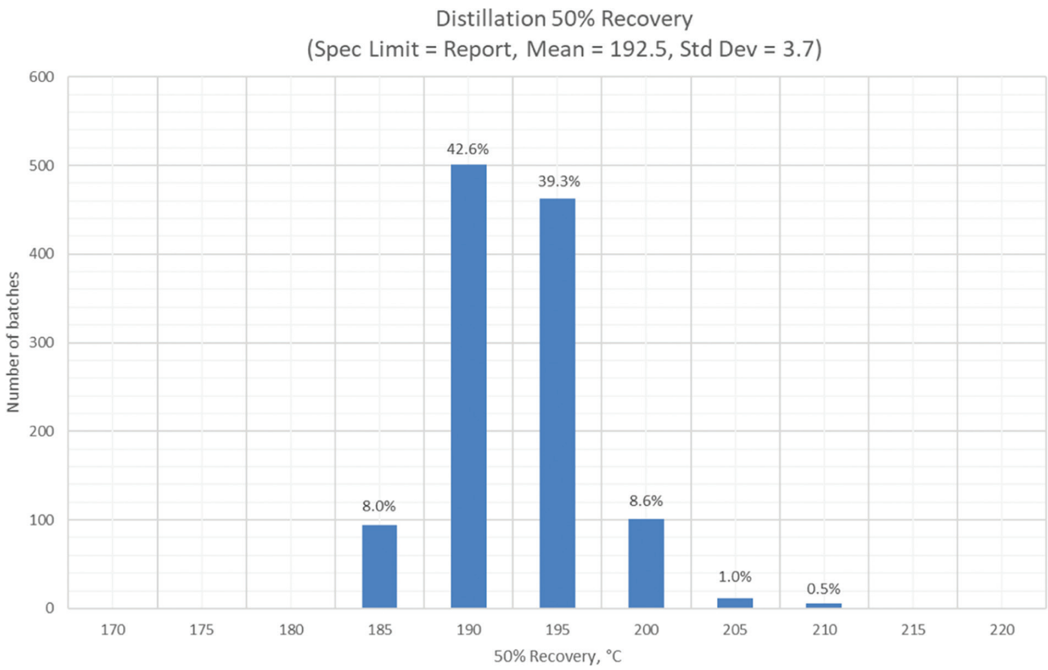

Figure B.19: Distillation 50 % recovery histogram (2016)

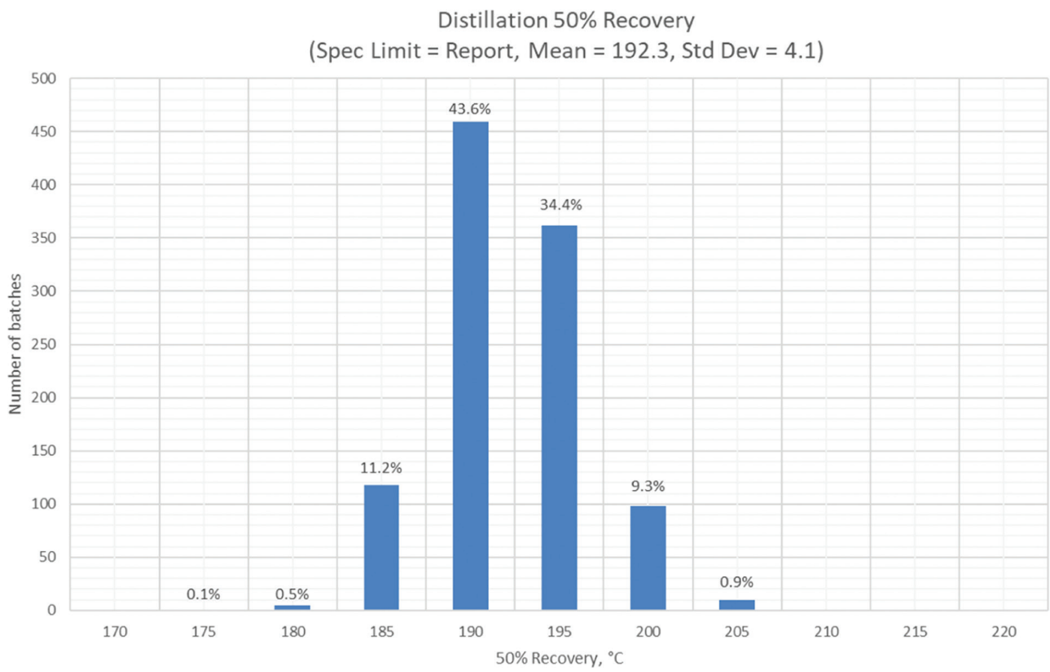

Figure B.20: Distillation 50 % recovery histogram (2017)

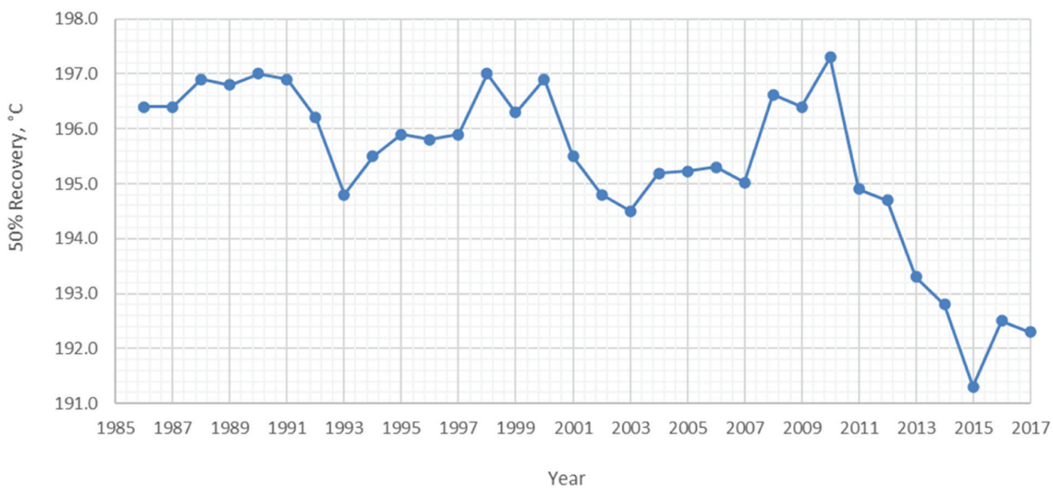

Figure B.21: Distillation 50 % recovery trend of the annual mean graph

B.8 DISTILLATION 90 % RECOVERY

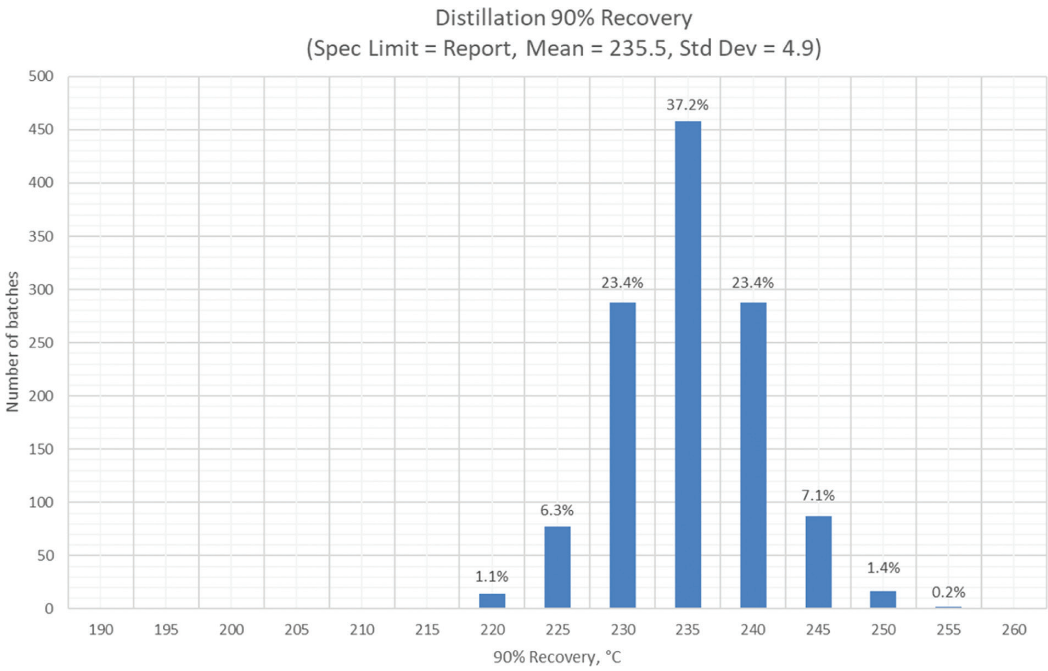

Figure B.22: Distillation 90 % recovery histogram (2016)

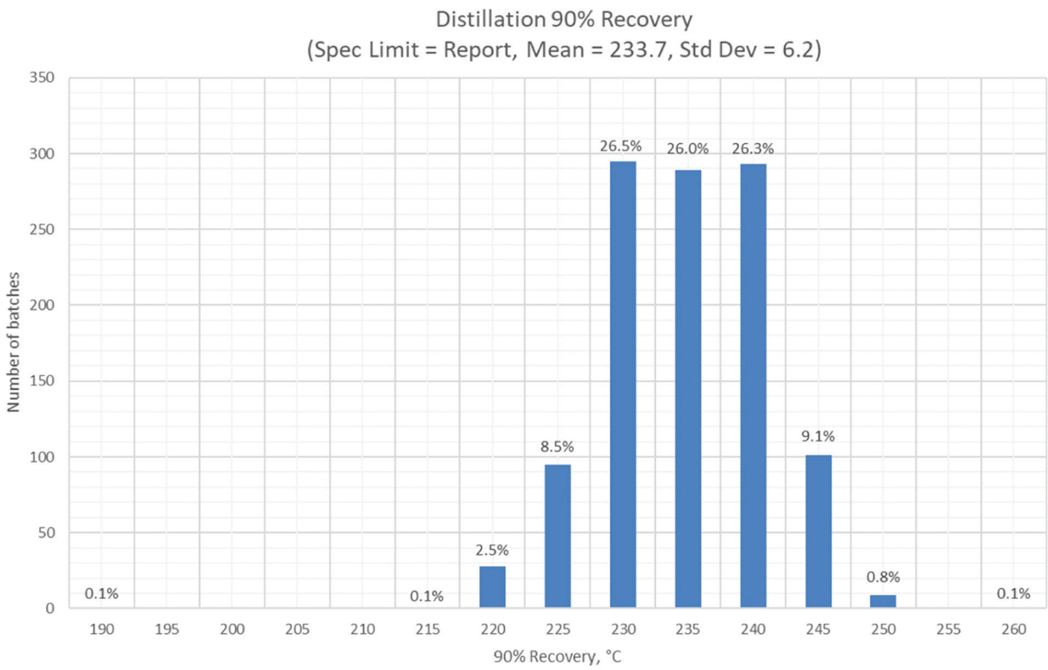

Figure B.23: Distillation 90 % recovery histogram (2017)

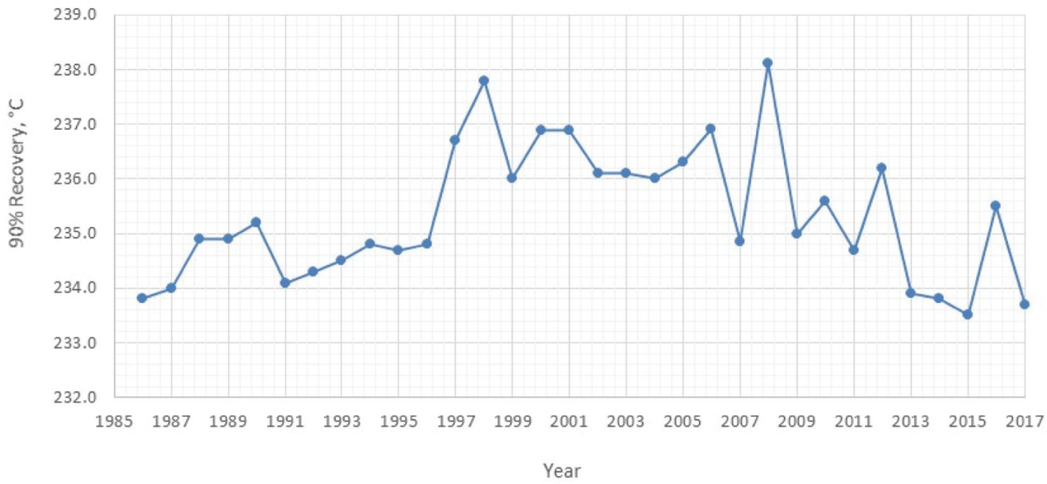

Figure B.24: Distillation 90 % recovery trend of the annual mean graph

B.9 DISTILLATION FBP

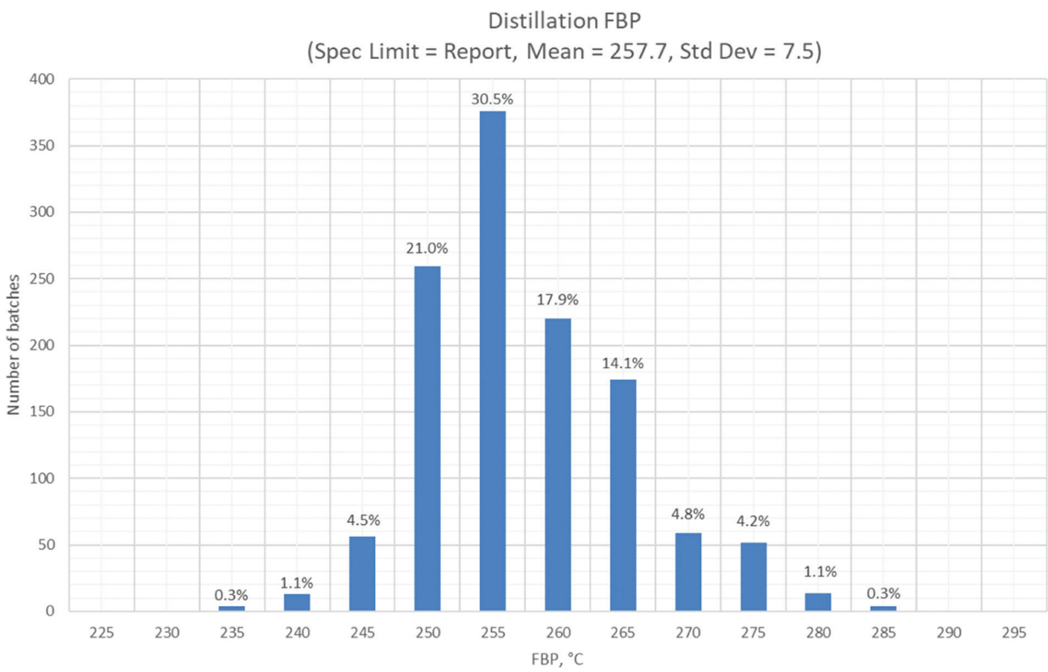

Figure B.25: Distillation FBP histogram (2016)

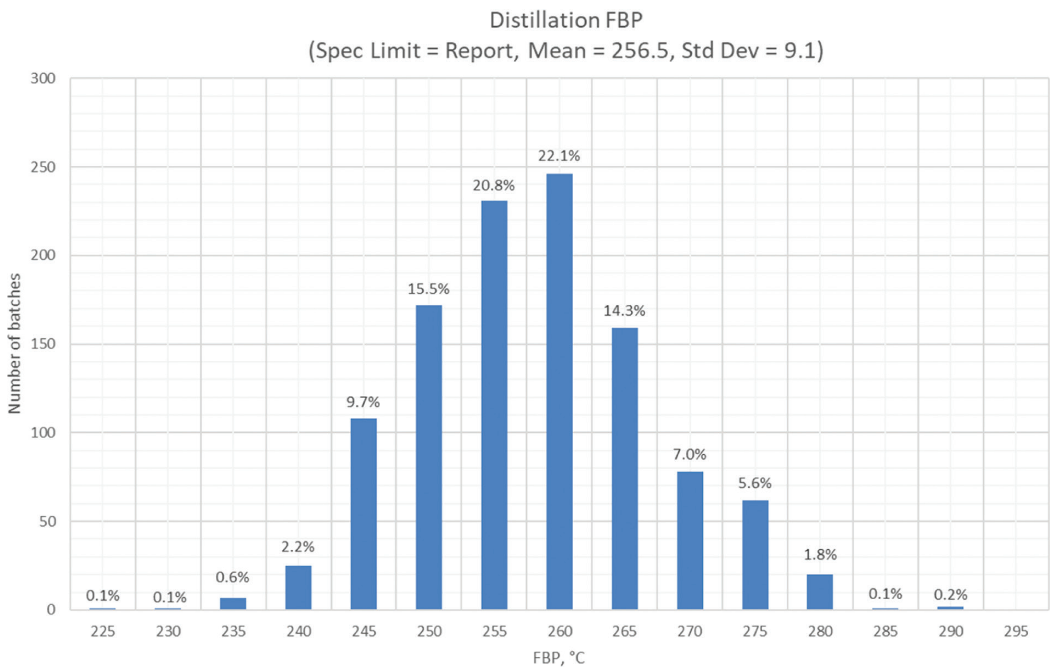

Figure B.26: Distillation FBP histogram (2017)

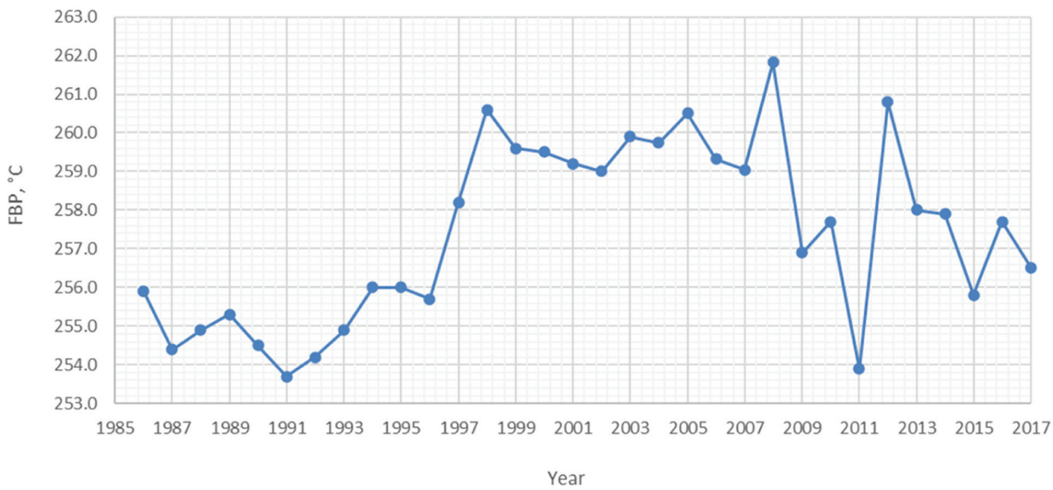

Figure B.27: Distillation FBP trend of the annual mean graph

B.10 DISTILLATION RANGE

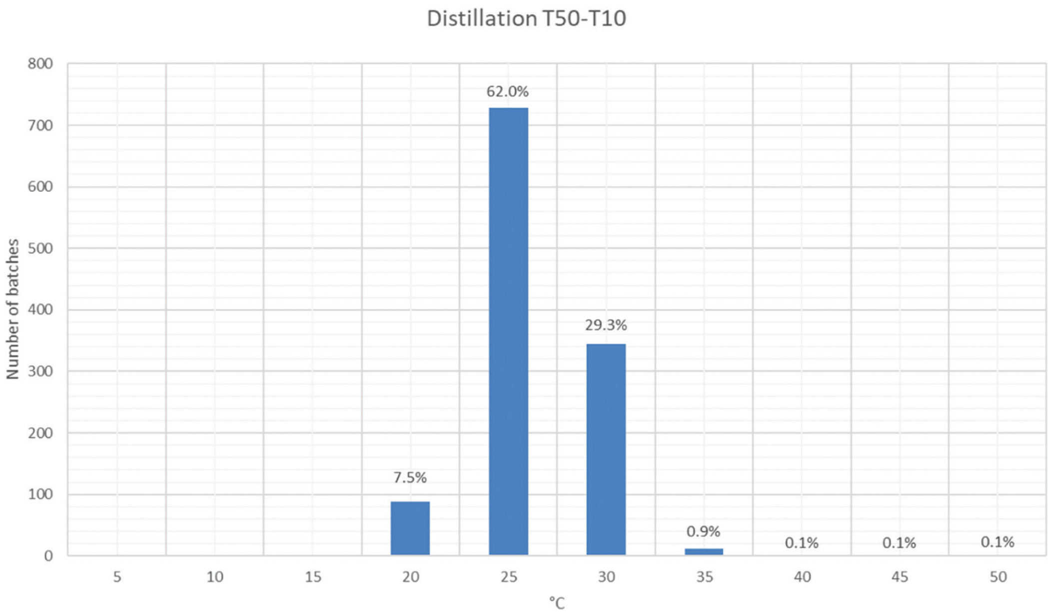

Figure B.28: Distillation T50-T10 (2016)

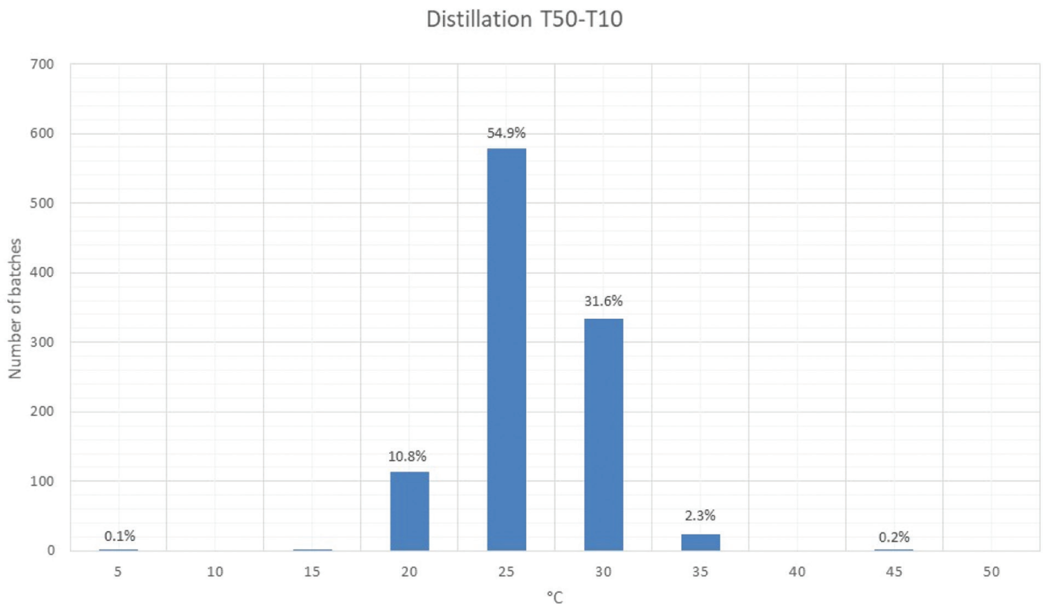

Figure B.29: Distillation T50-T10 (2017)

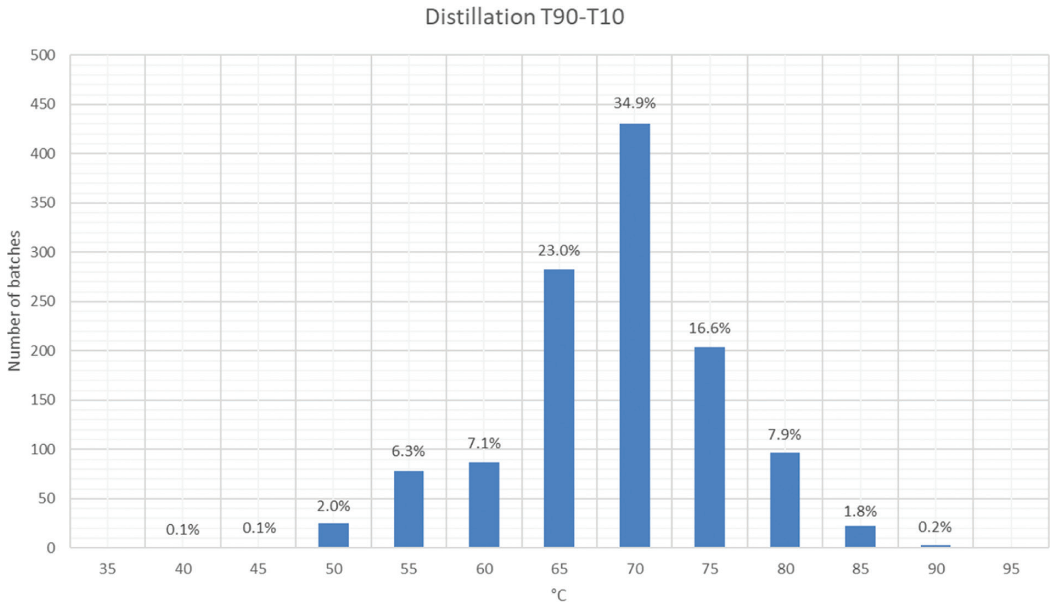

Figure B.30: Distillation T90-T10 (2016)

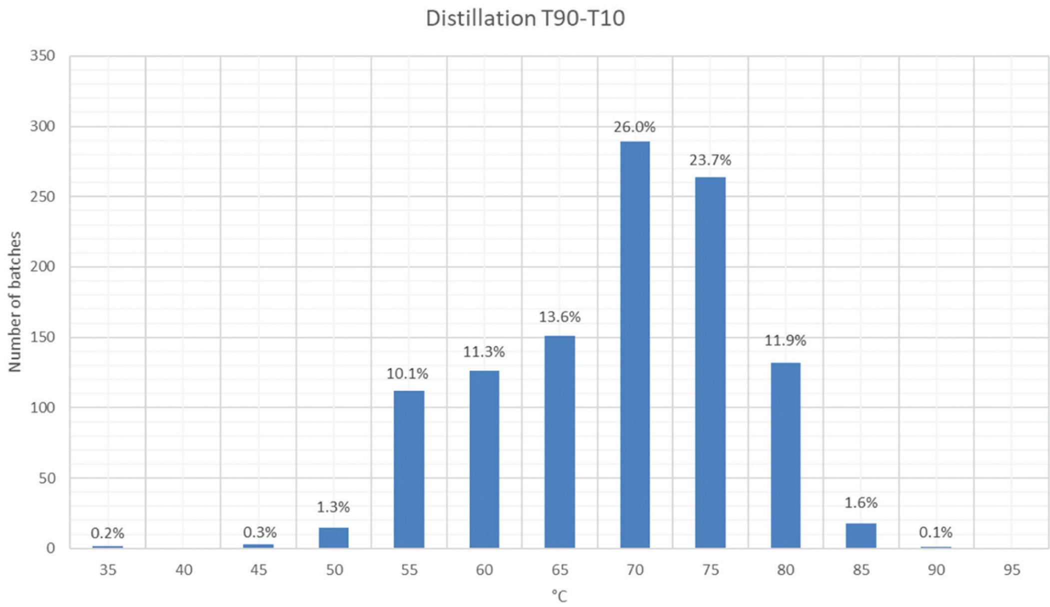

Figure B.31: Distillation T90-T10 (2017)

B.11 FLASH POINT

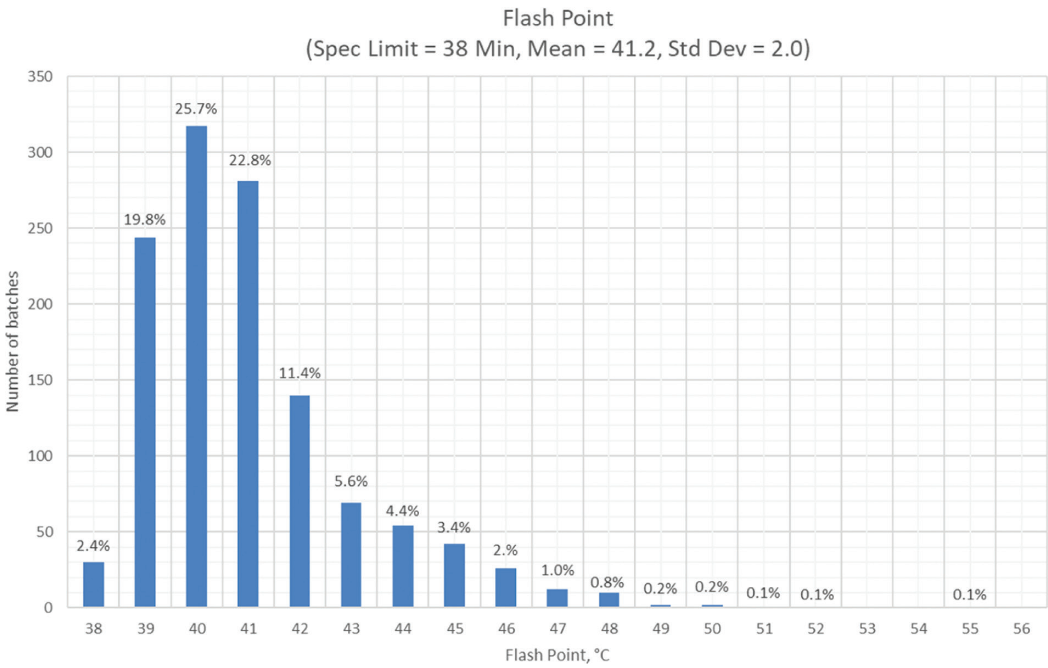

Figure B.32: Flash point histogram (2016)

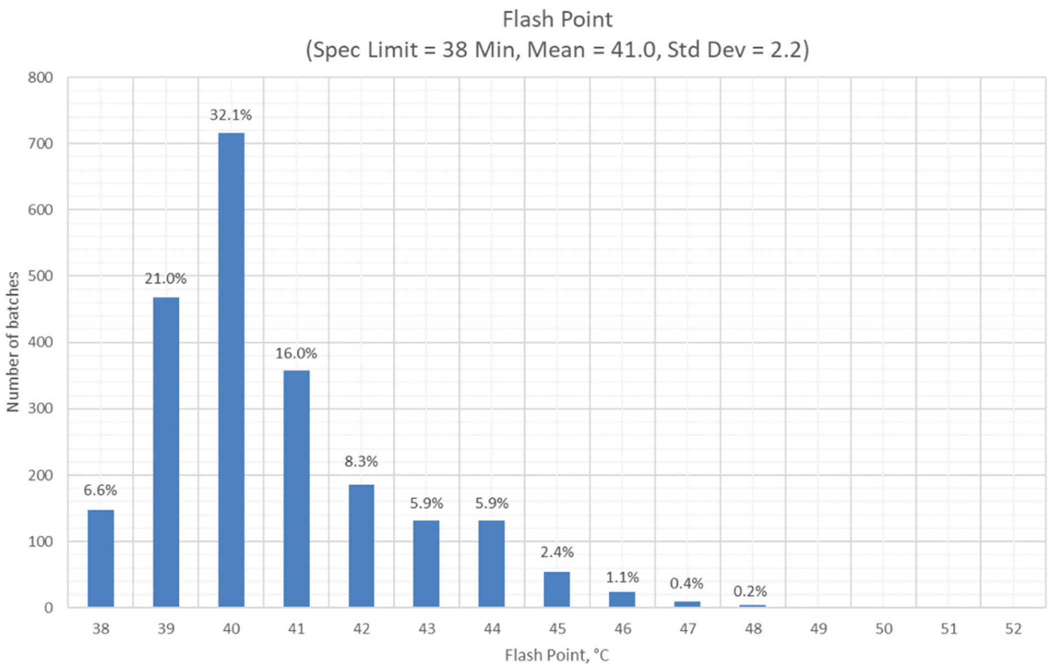

Figure B.33: Flash point histogram (2017)

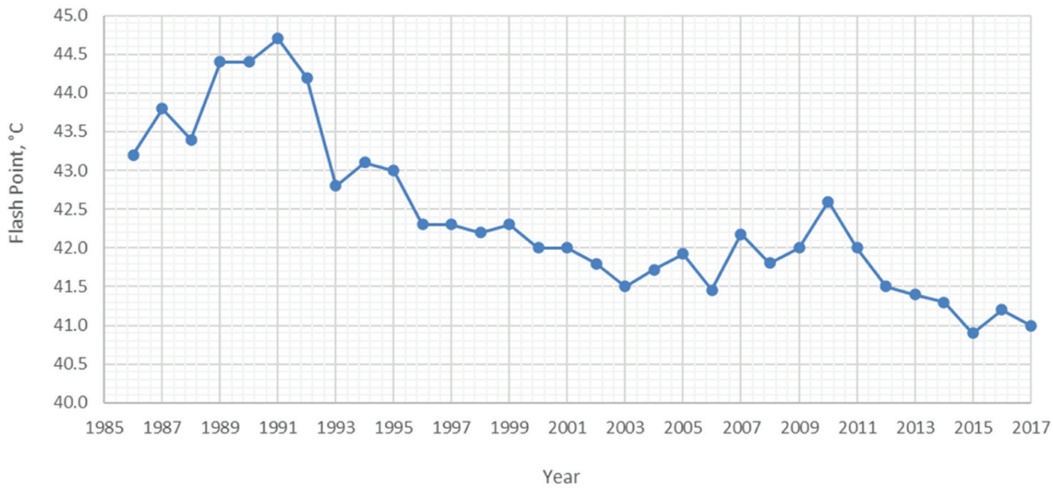

Figure B.34: Flash point trend of the annual mean graph

B.12 DENSITY AT 15 °C

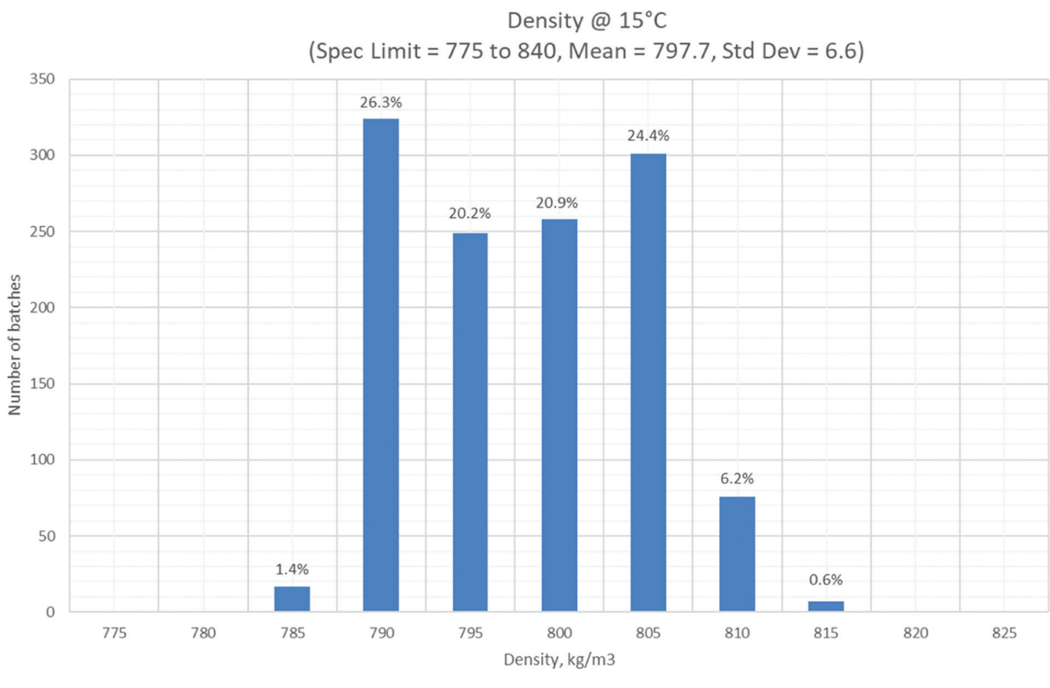

Figure B.35: Density histogram (2016)

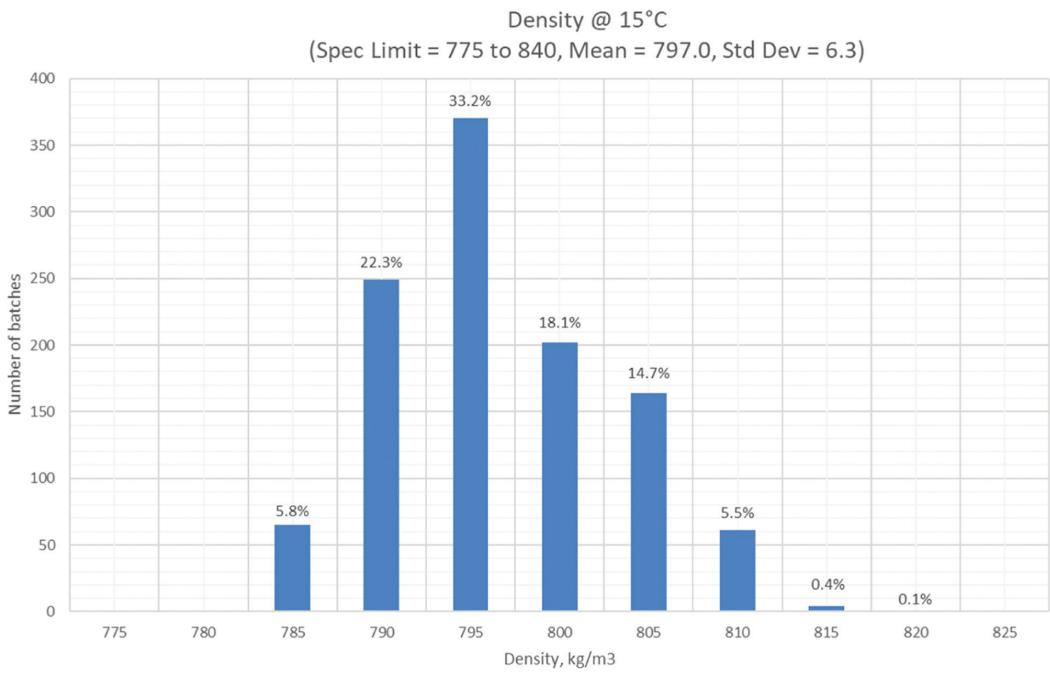

Figure B.36: Density histogram (2017)

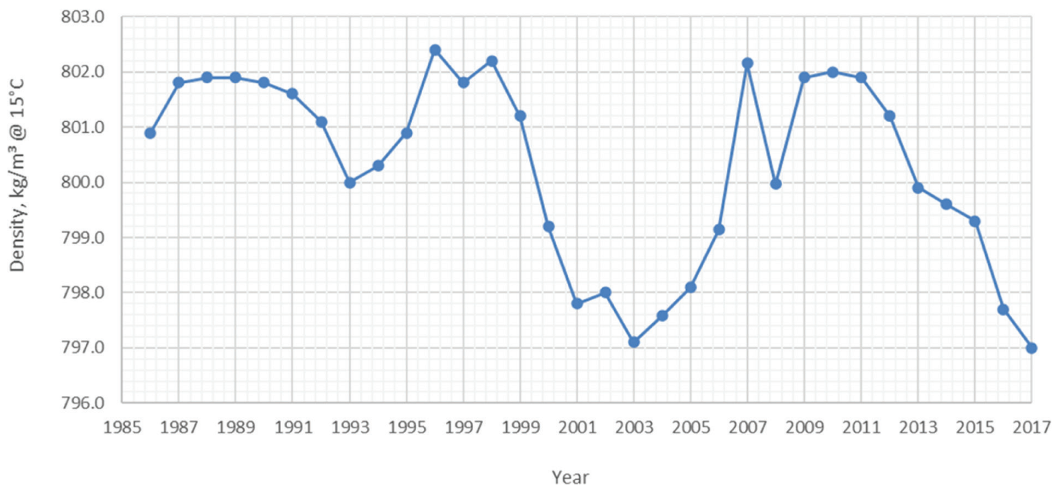

Figure B.37: Density trend of the annual mean graph

B.13 FREEZING POINT

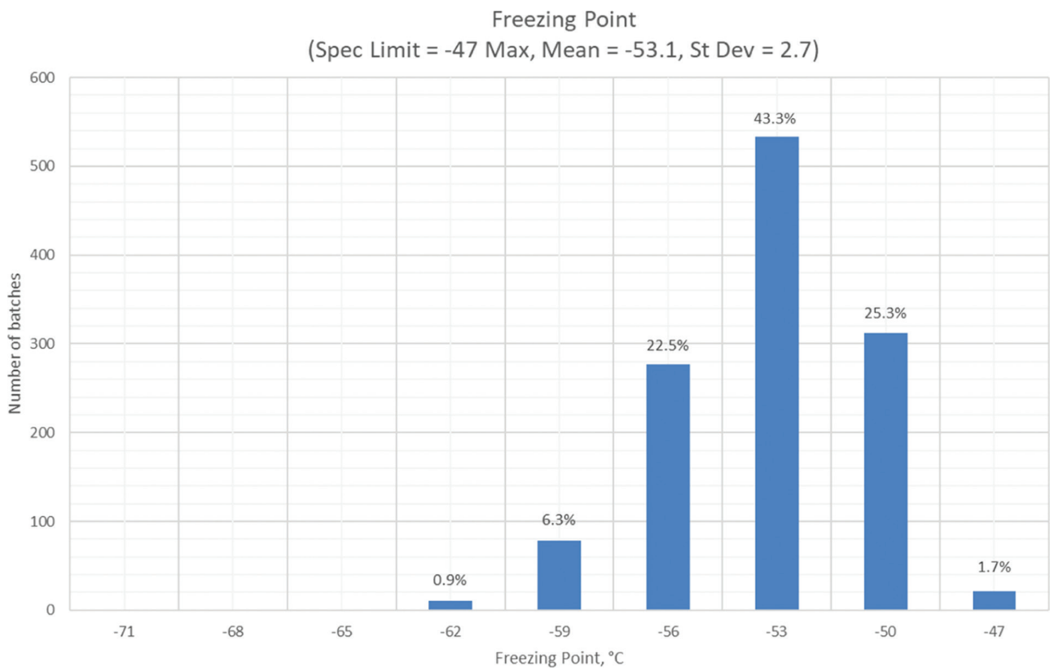

Figure B.38: Freezing point histogram (2016)

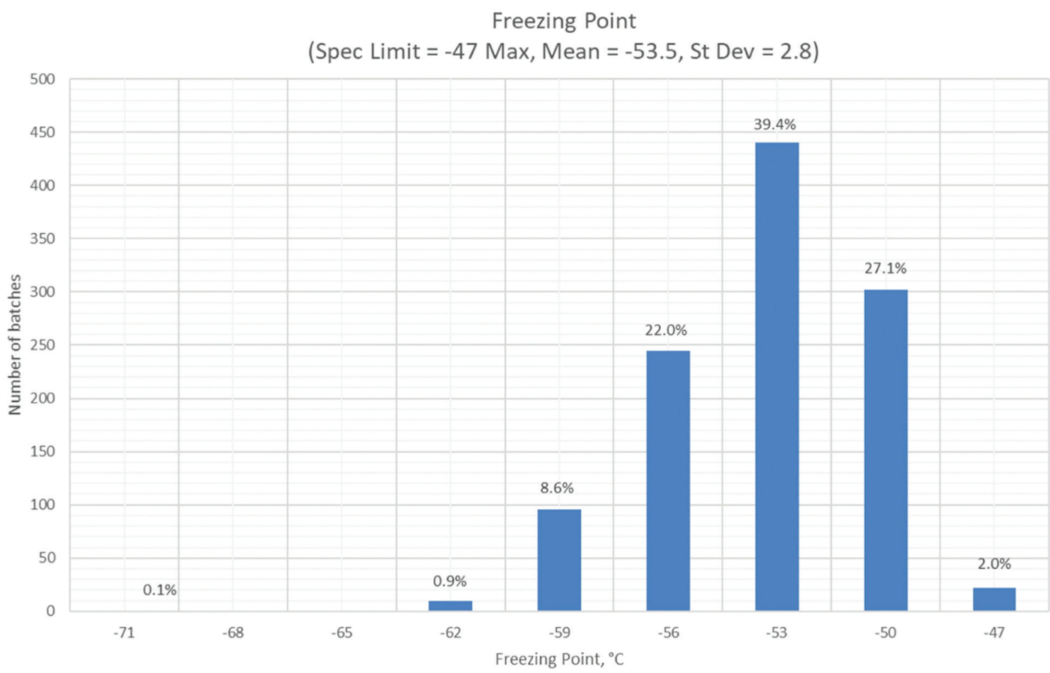

Figure B.39: Freezing point histogram (2017)

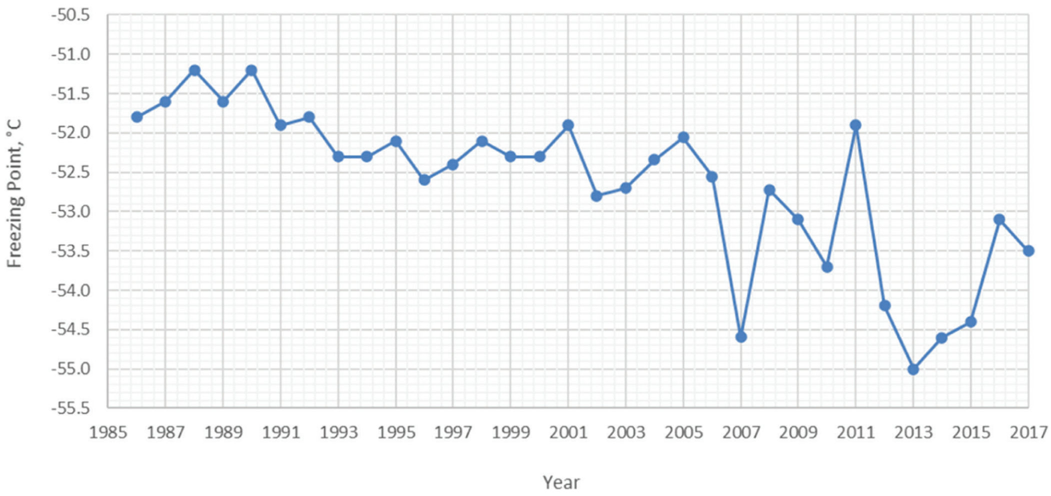

Figure B.40: Freezing point trend of the annual mean graph

B.14 Kinematic viscosity at –20 °C

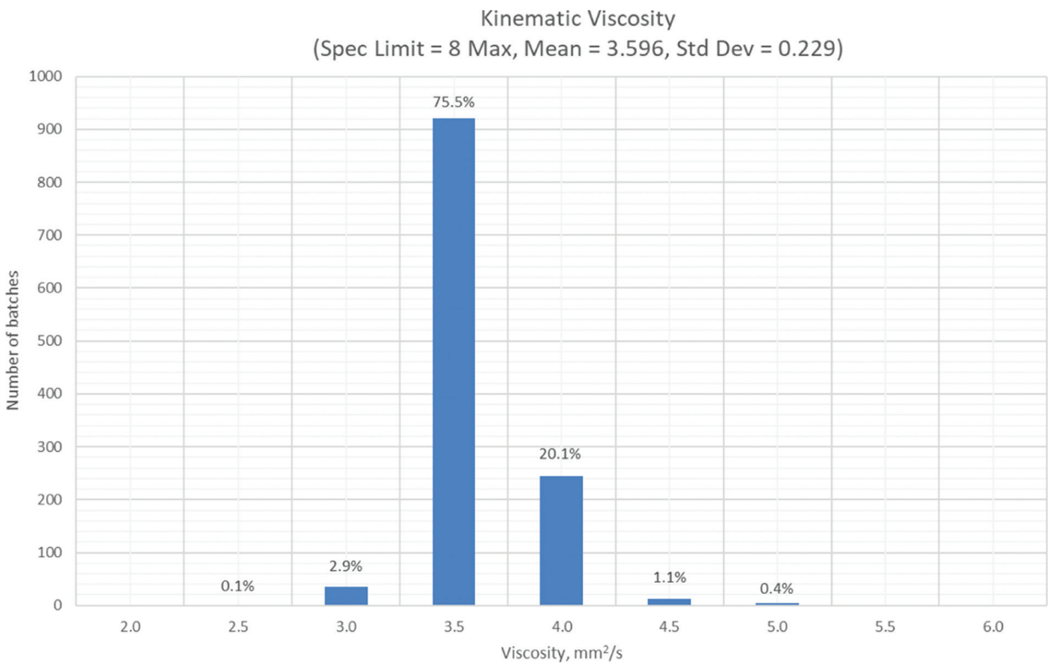

Figure B.41: Kinematic viscosity histogram (2016)

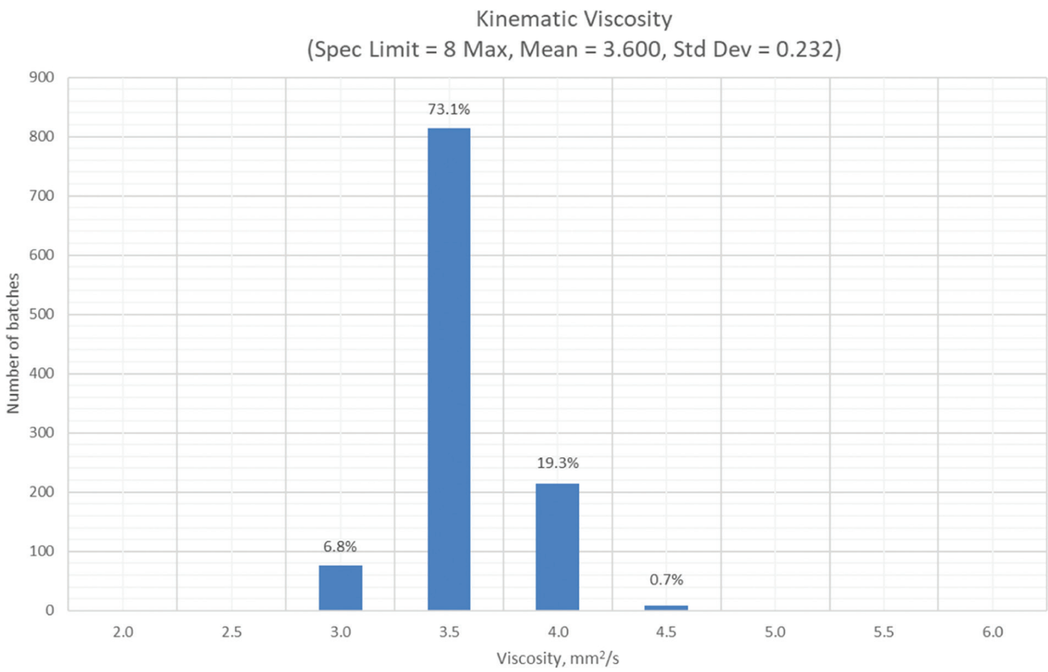

Figure B.42: Kinematic viscosity histogram (2017)

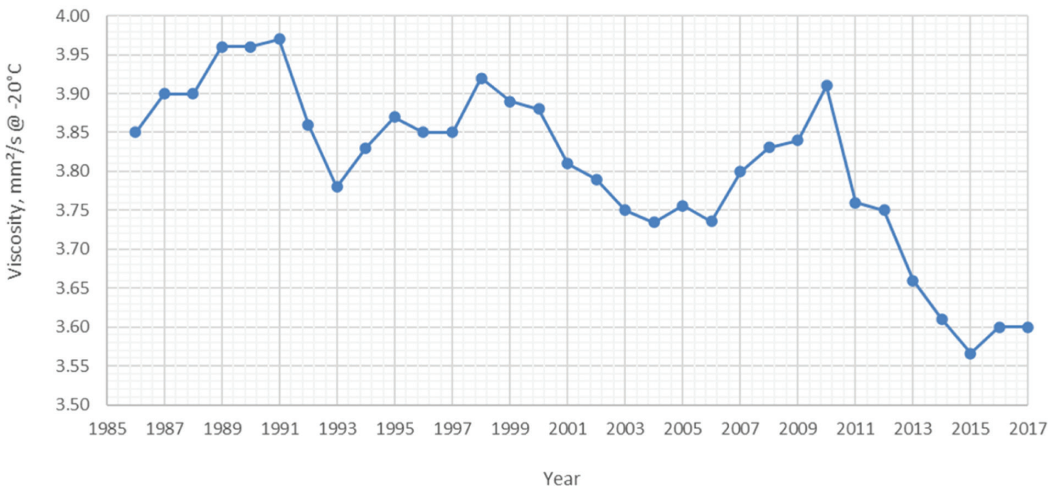

Figure B.43: Kinematic viscosity trend of the annual mean graph

B.15 SPECIFIC ENERGY

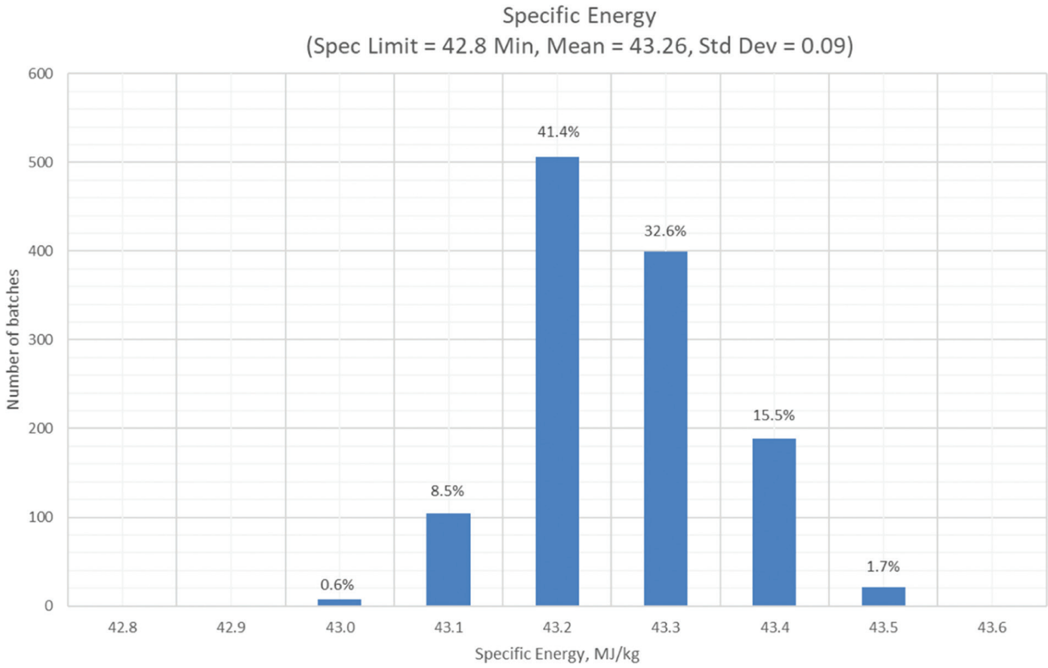

Figure B.44: Specific energy histogram (2016)

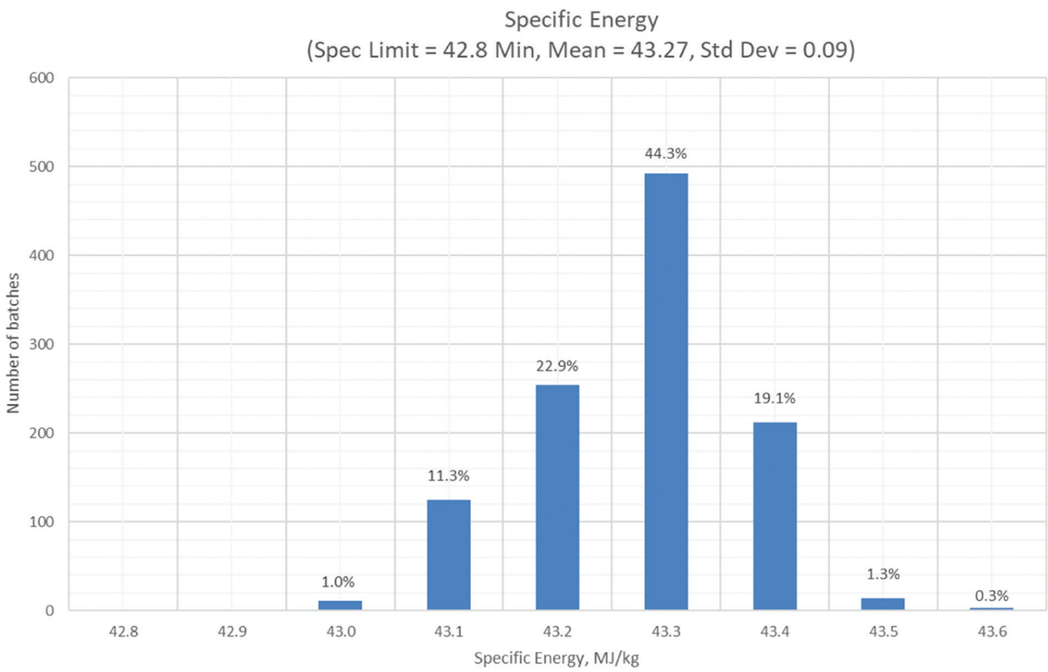

Figure B.45: Specific energy histogram (2017)

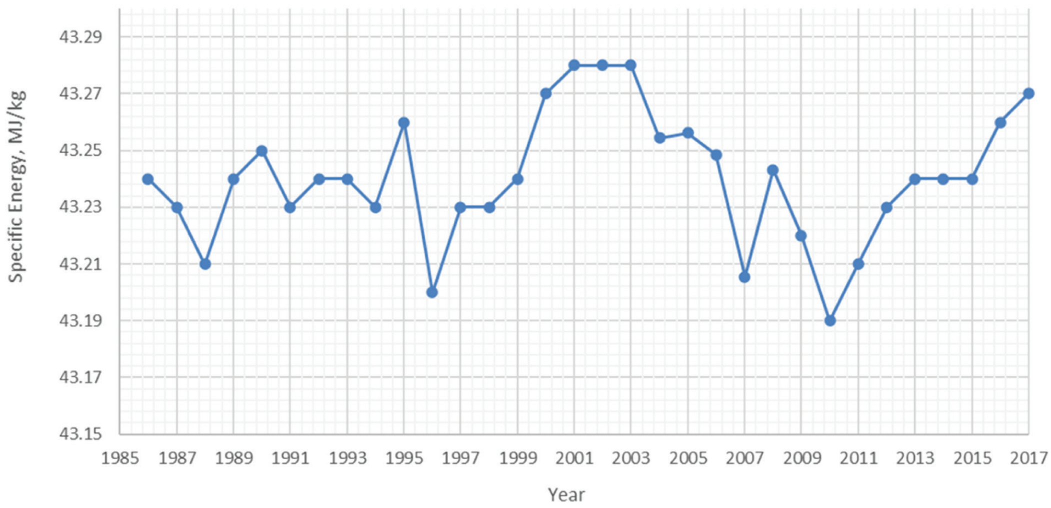

Figure B.46: Specific energy trend of the annual mean graph

B.16 SMOKE POINT

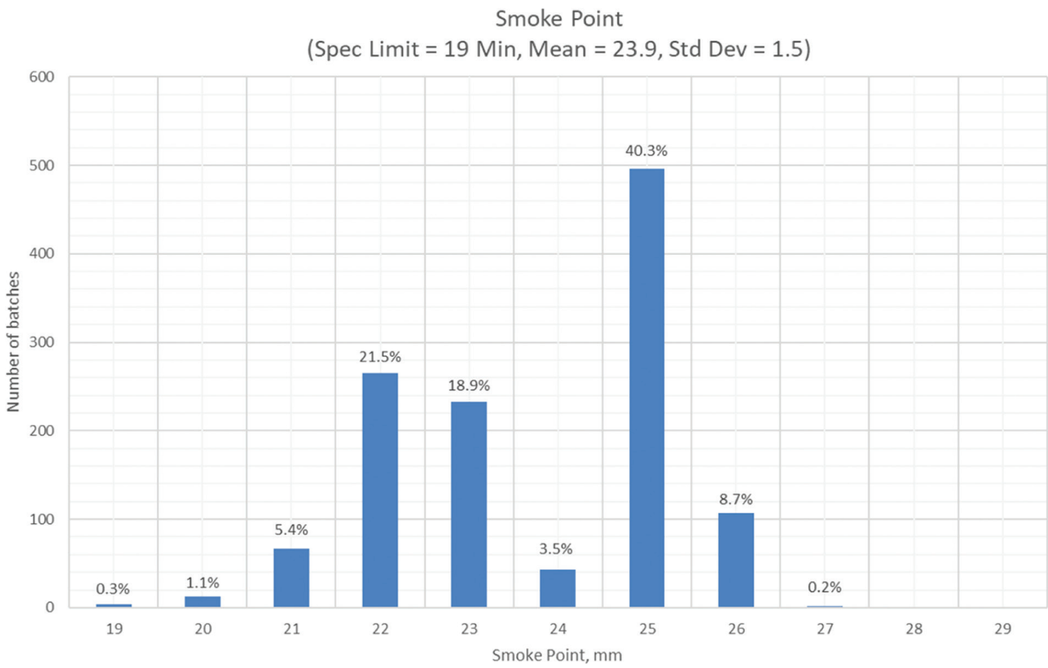

Figure B.47: Smoke point histogram (2016)

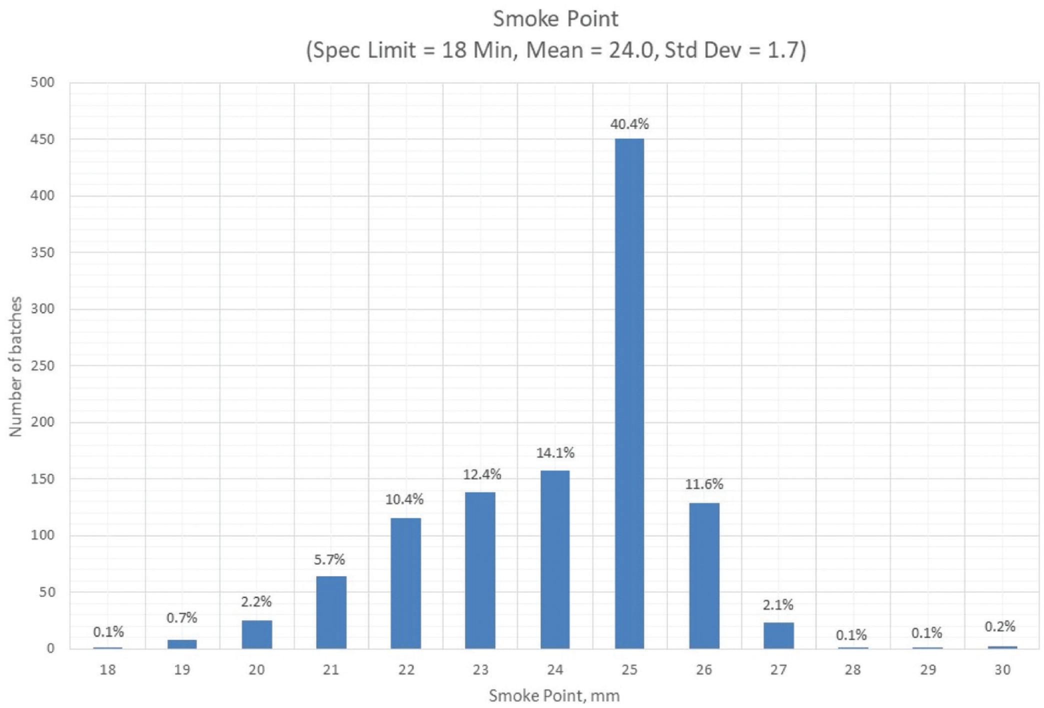

Figure B.48: Smoke point histogram (2017)

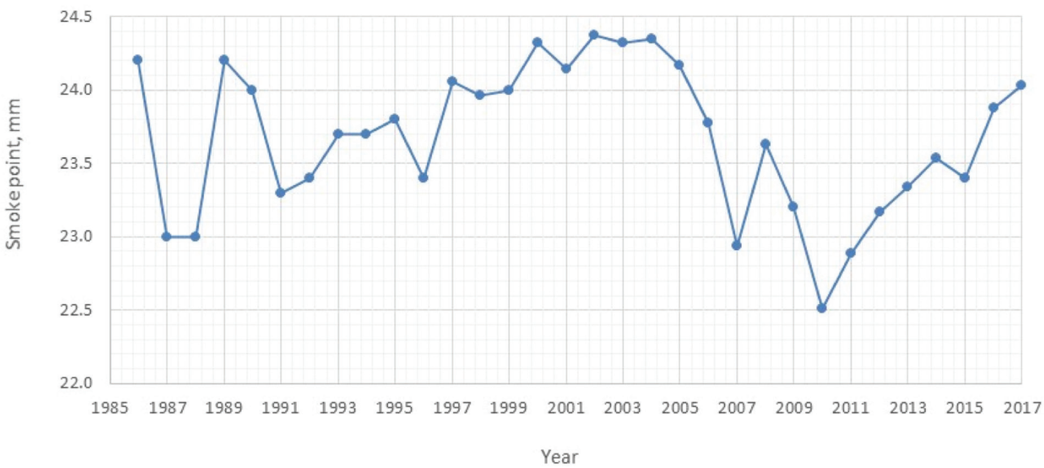

Figure B.49: Smoke point trend of the annual mean graph

B.17 NAPHTHALENES

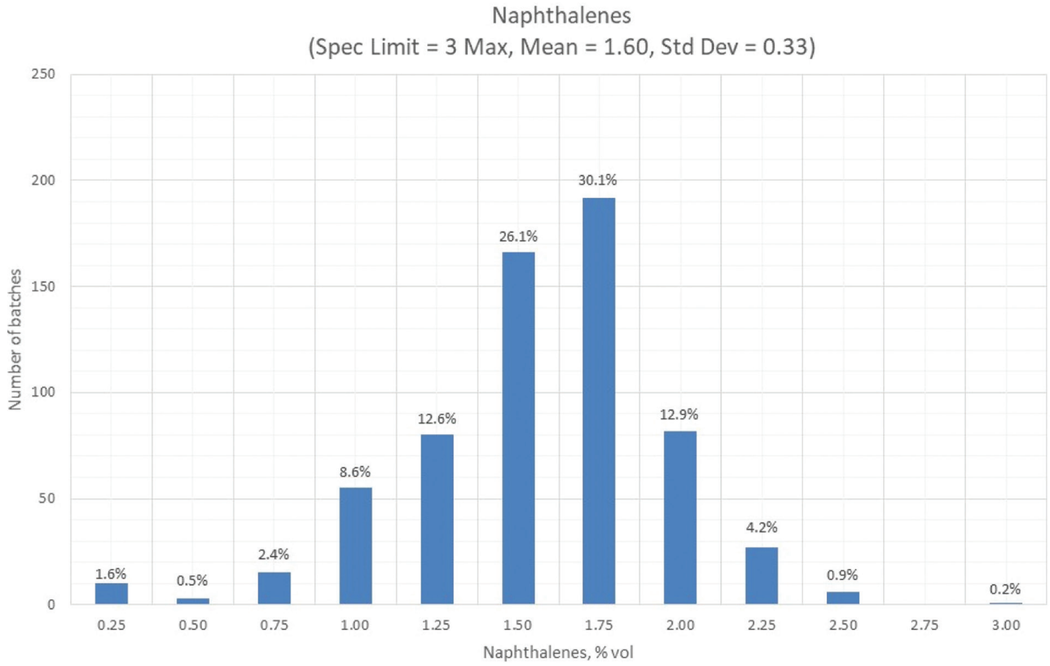

Figure B.50: Naphthalenes histogram (2016)

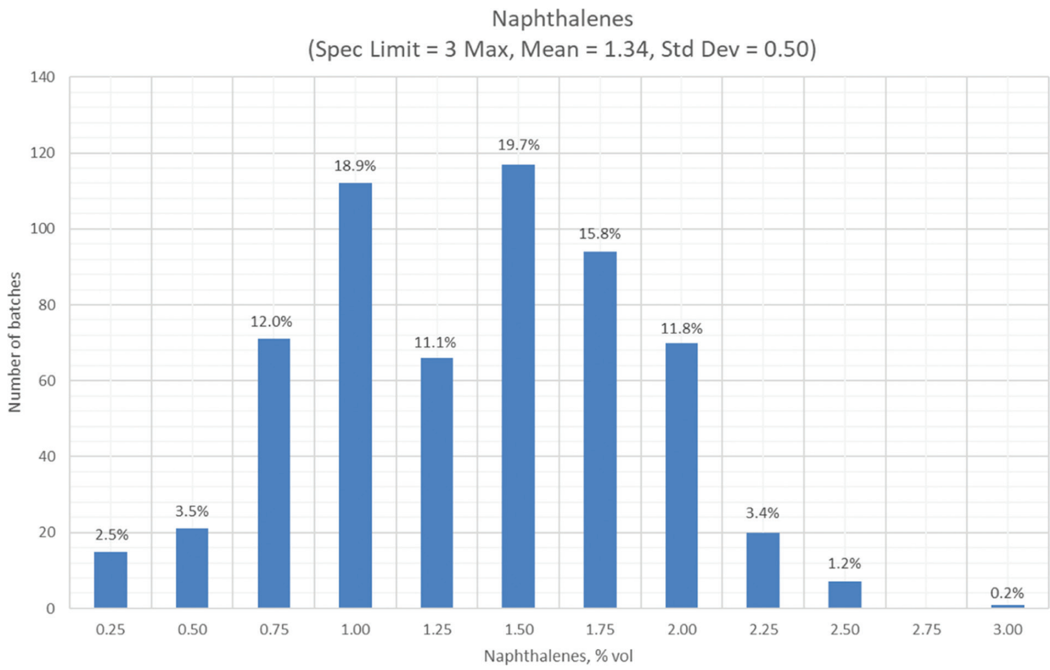

Figure B.51: Naphthalenes histogram (2017)

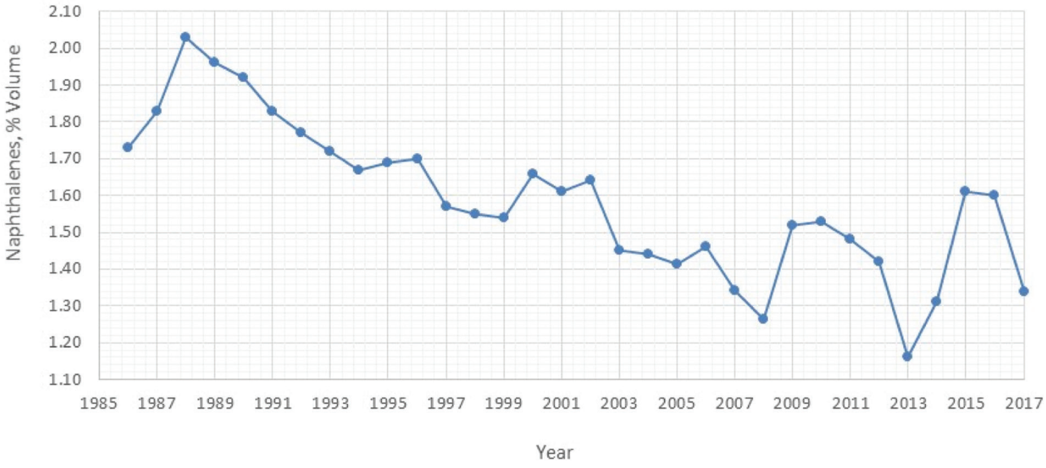

Figure B.52: Naphthalenes trend of the annual mean graph

B.18 EXISTENT GUM

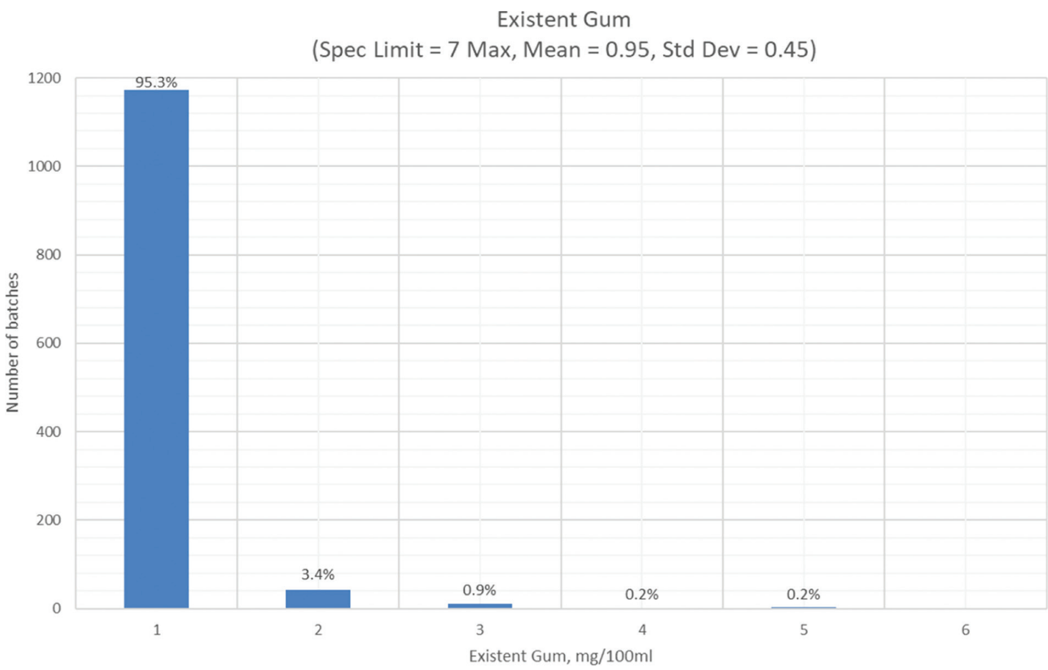

Figure B.53: Existent gum histogram (2016)

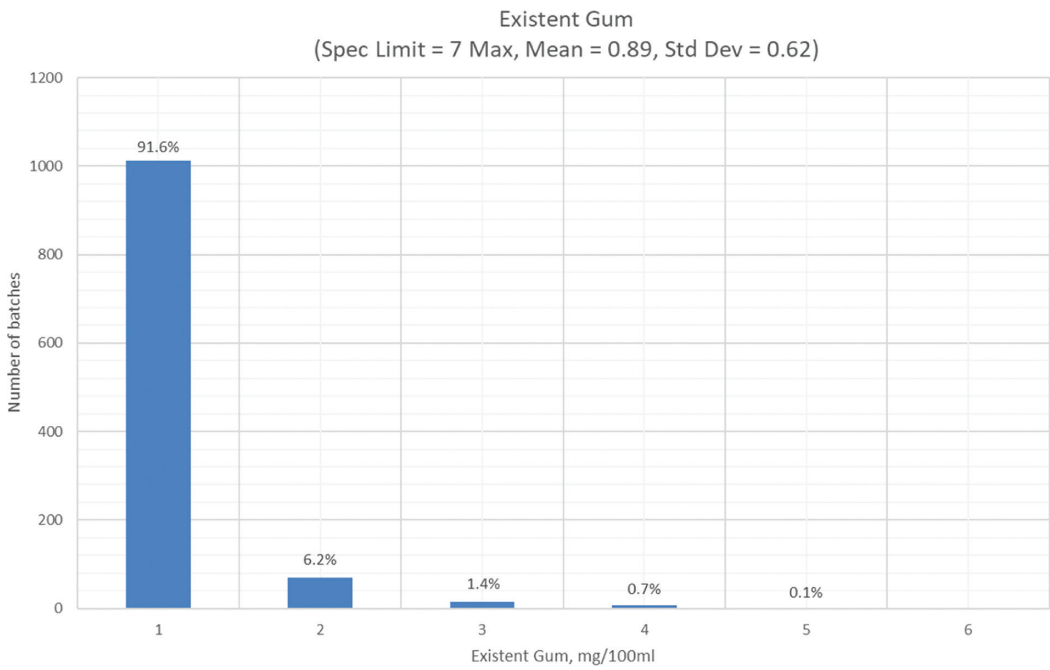

Figure B.54: Existent gum histogram (2017)

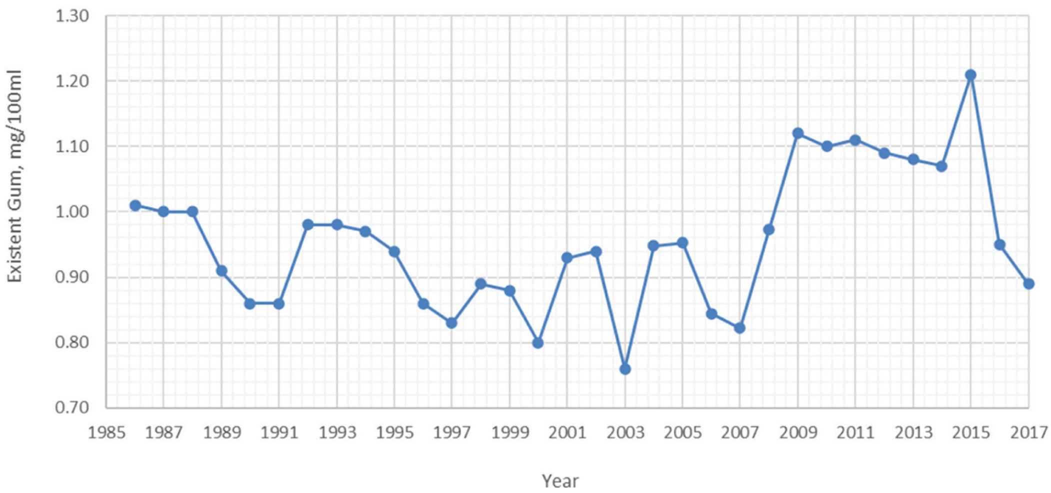

Figure B.55: Existent gum trend of the annual mean graph

B.19 MSEP®

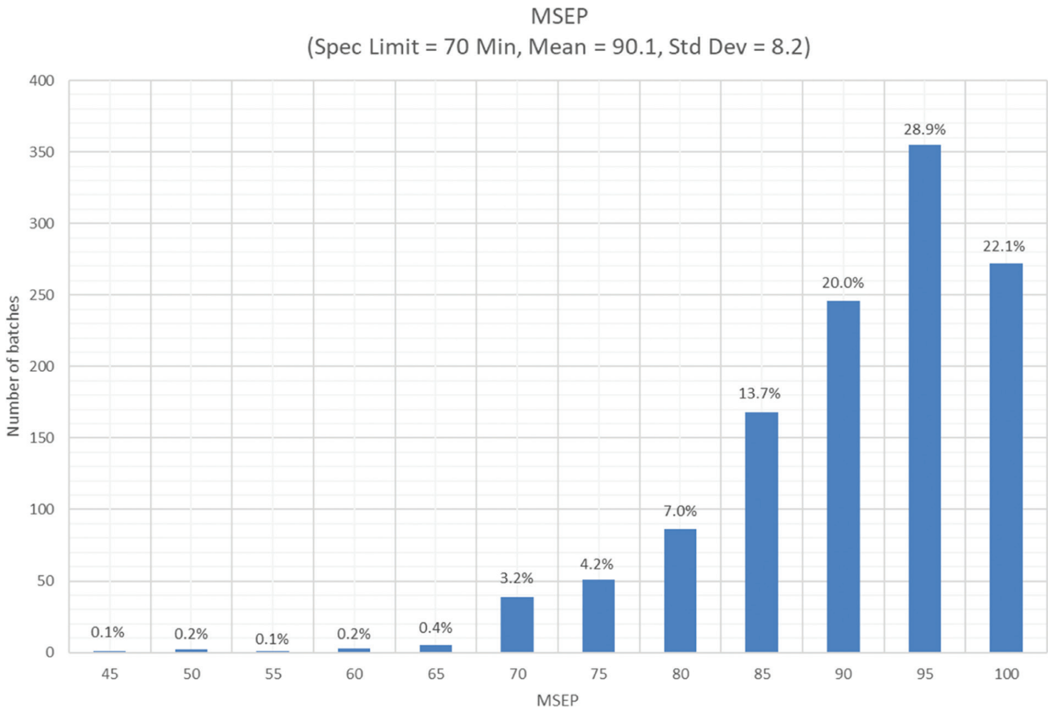

Figure B.56: MSEP® histogram (2016)

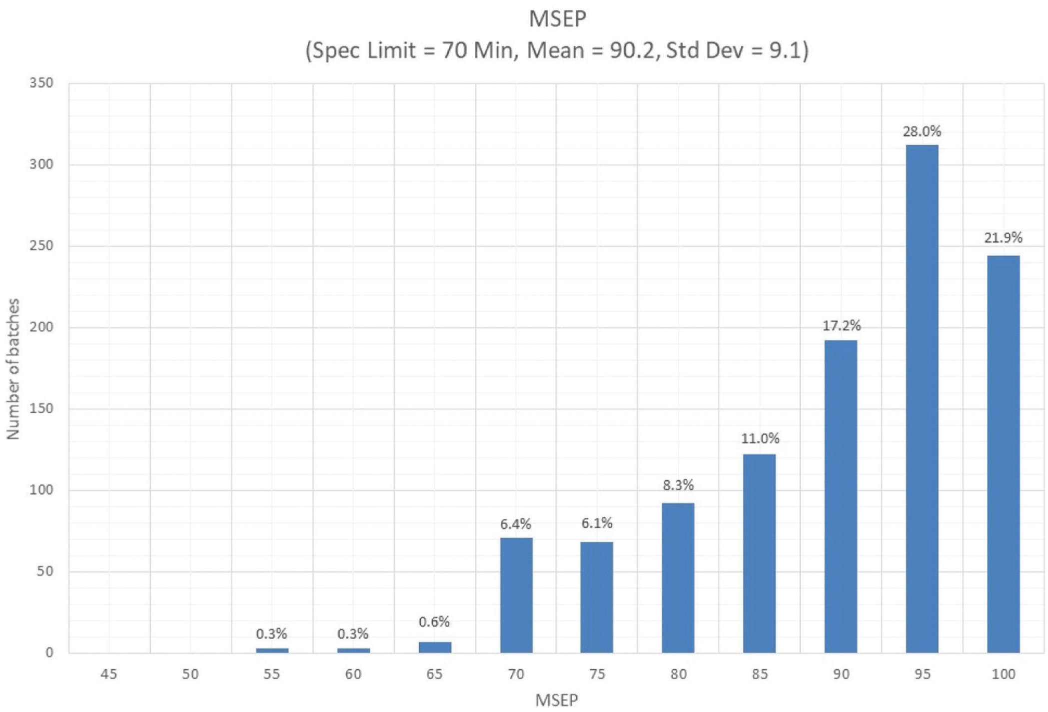

Figure B.57: MSEP® histogram (2017)

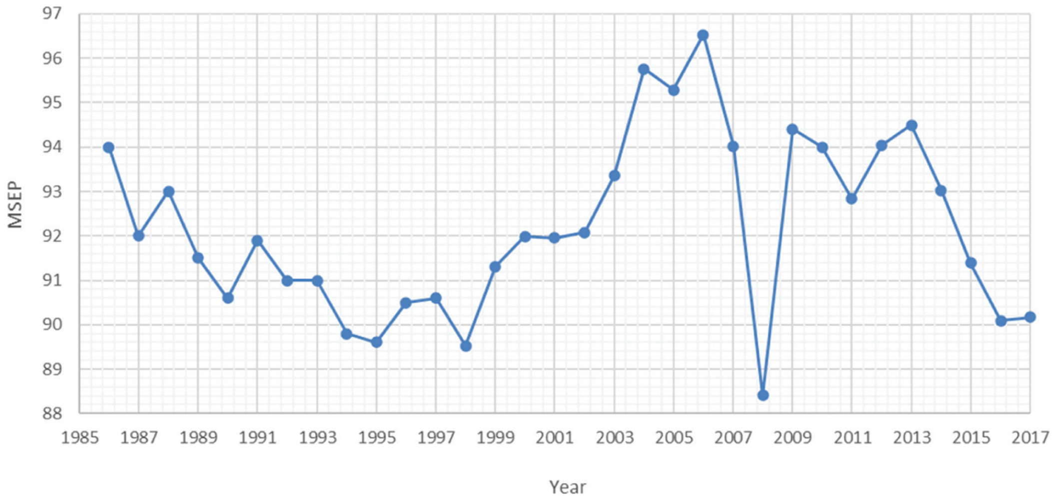

Figure B.58: MSEP® trend of the annual mean graph

B.20 PARTICULATE (GRAVIMETRIC)

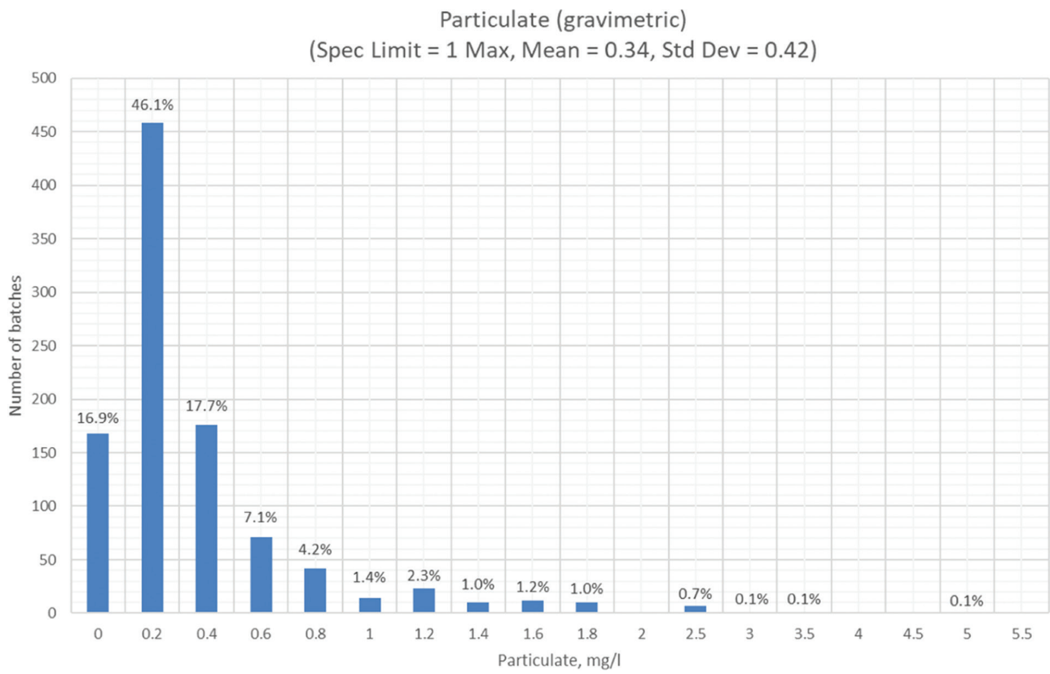

Figure B.59: Particulate histogram (2016)

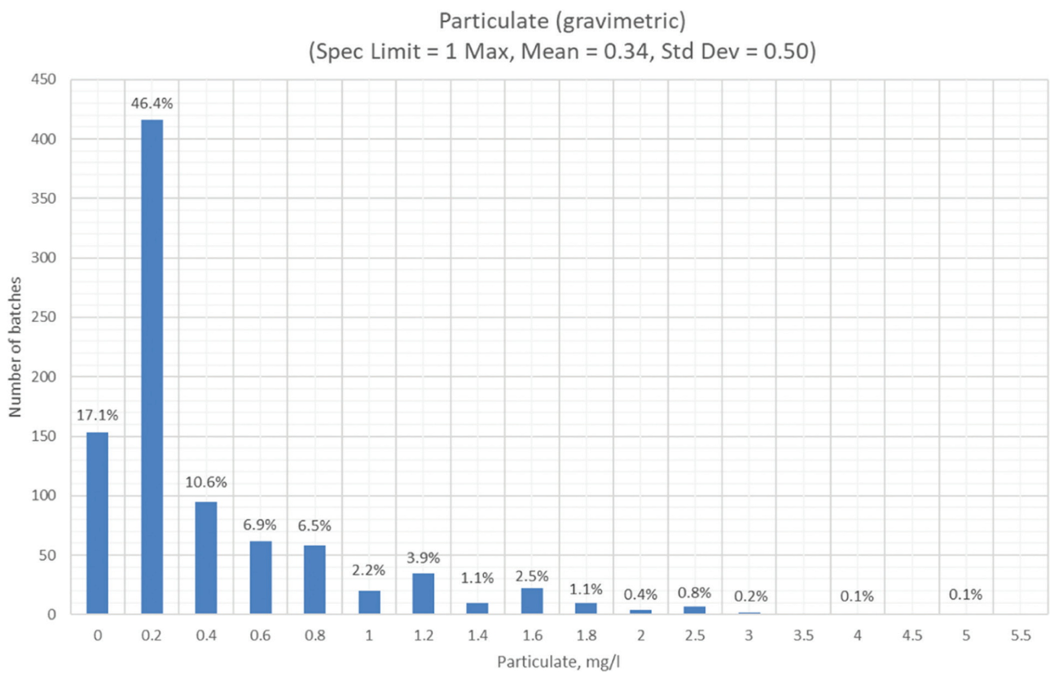

Figure B.60: Particulate histogram (2017)

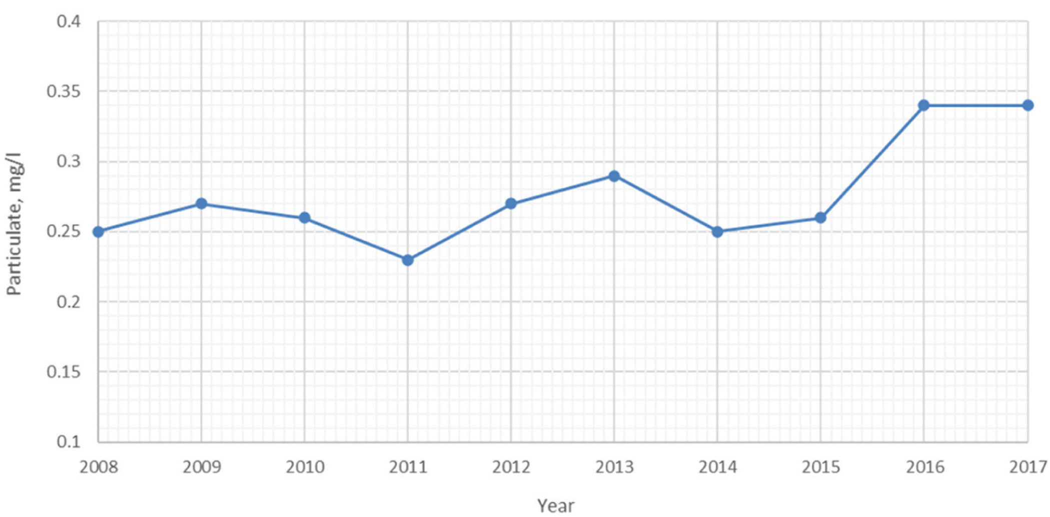

Figure B.61: Particulate trend of the annual mean graph

B.21 SAYBOLT COLOUR

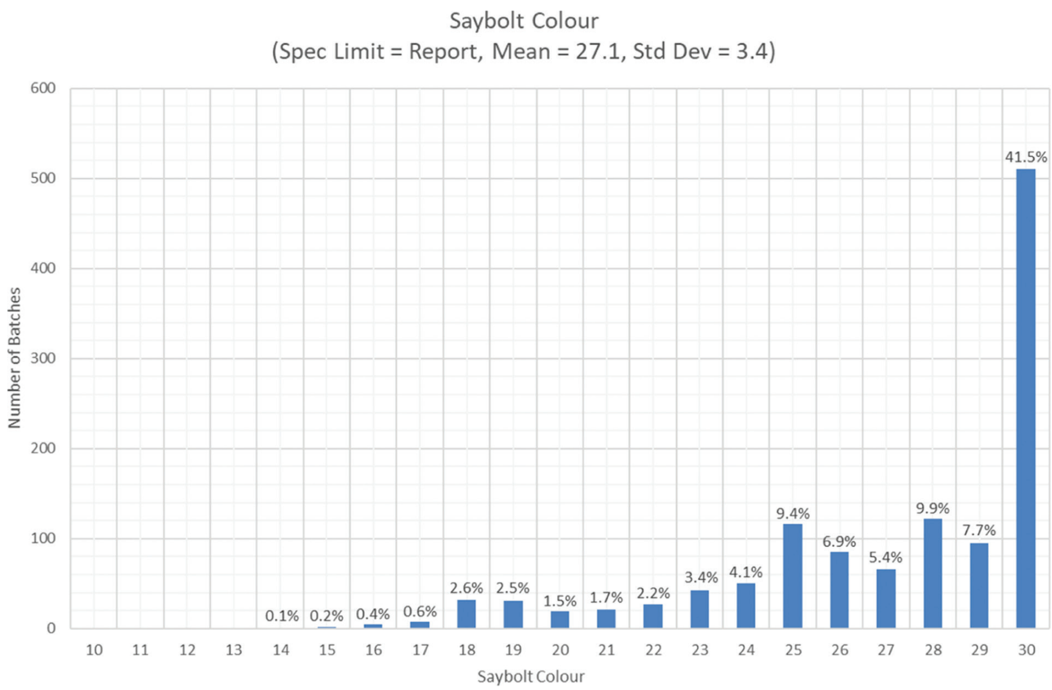

Figure B.62: Saybolt colour histogram (2016)

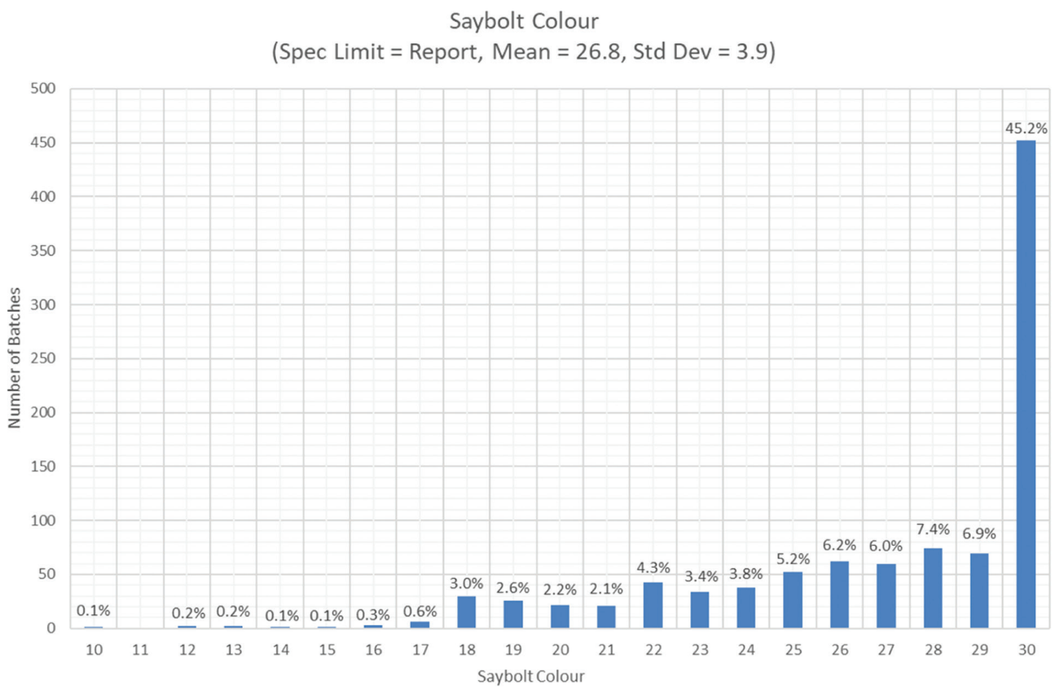

Figure B.63: Saybolt colour histogram (2017)

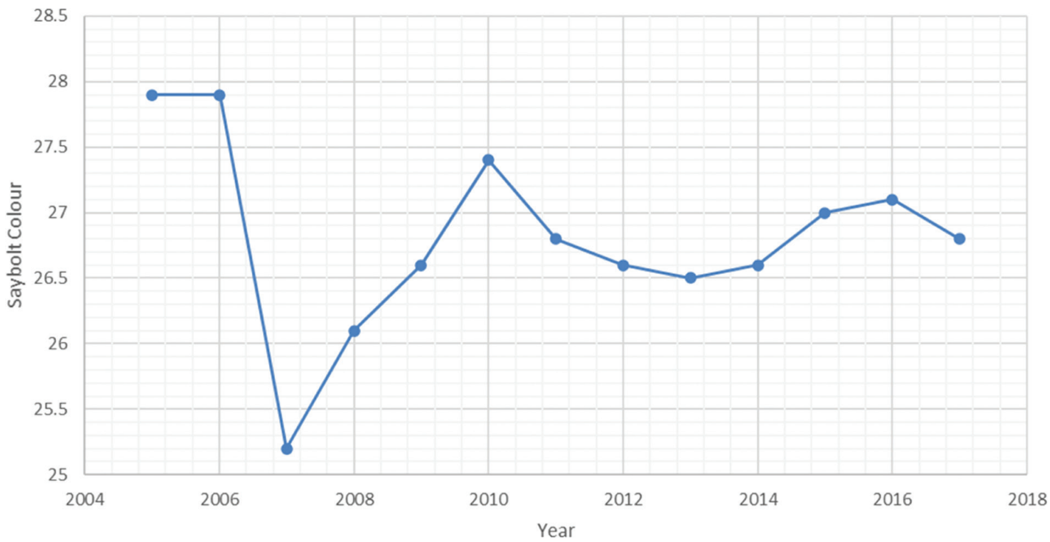

Figure B.64: Saybolt colour trend of the annual mean graph

B.22 PARTICLE COUNTS

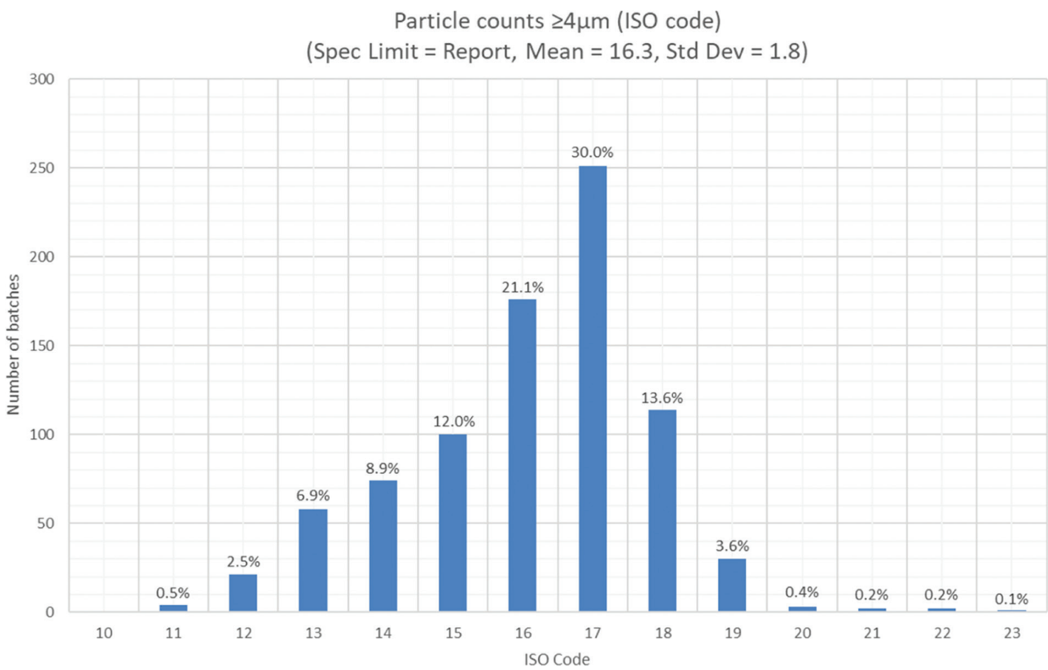

Figure B.65: Particle counts ≥4 µm ISO code (2016)

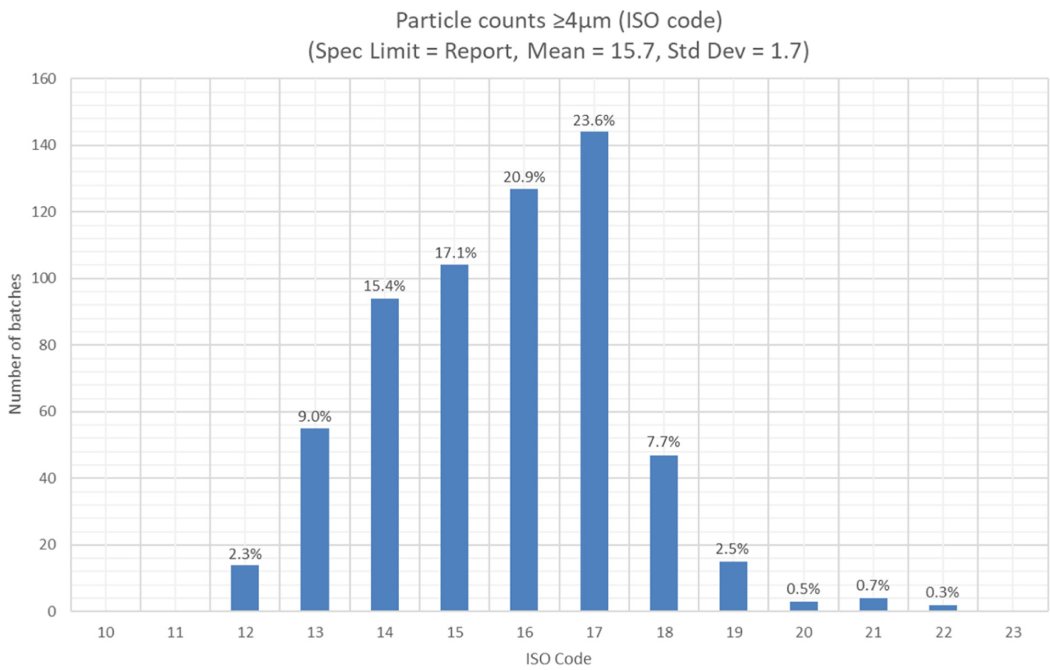

Figure B.66: Particle counts ≥4 µm ISO code (2017)

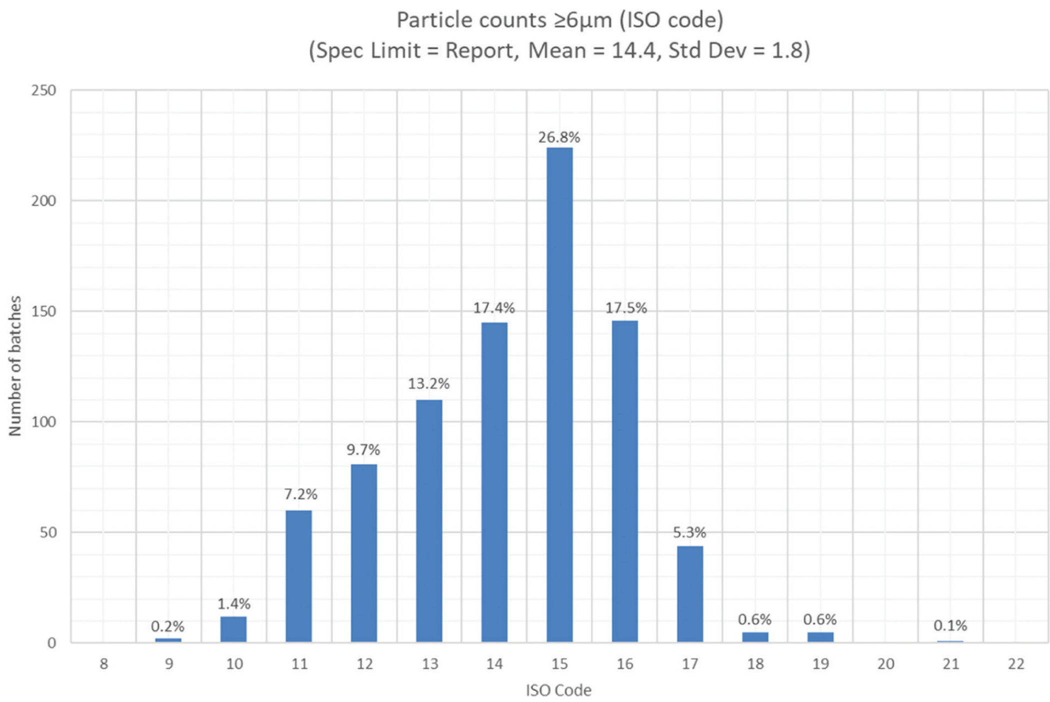

Figure B.67: Particle counts ≥6 µm ISO code (2016)

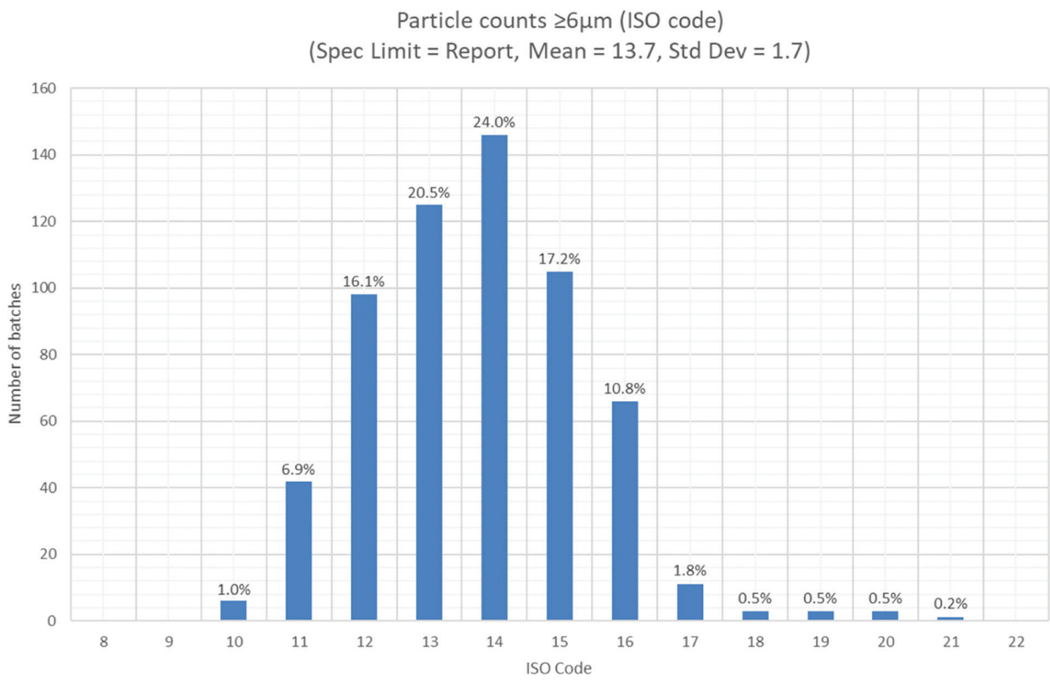

Figure B.68: Particle counts ≥6 μm ISO code (2017)

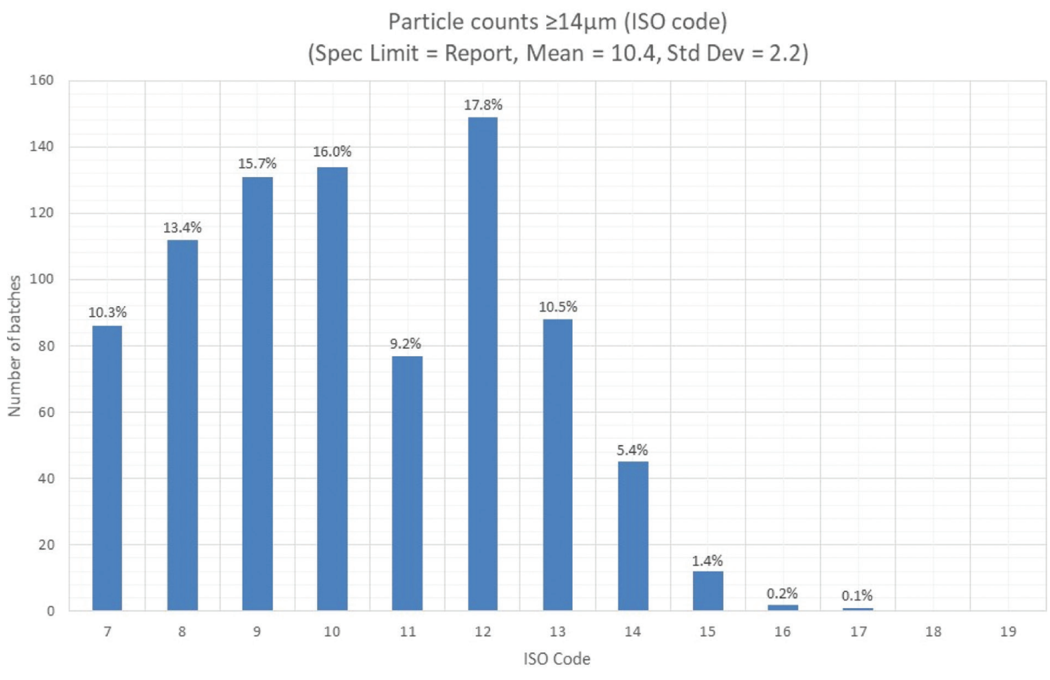

Figure B.69: Particle counts ≥14 μm ISO code (2016)

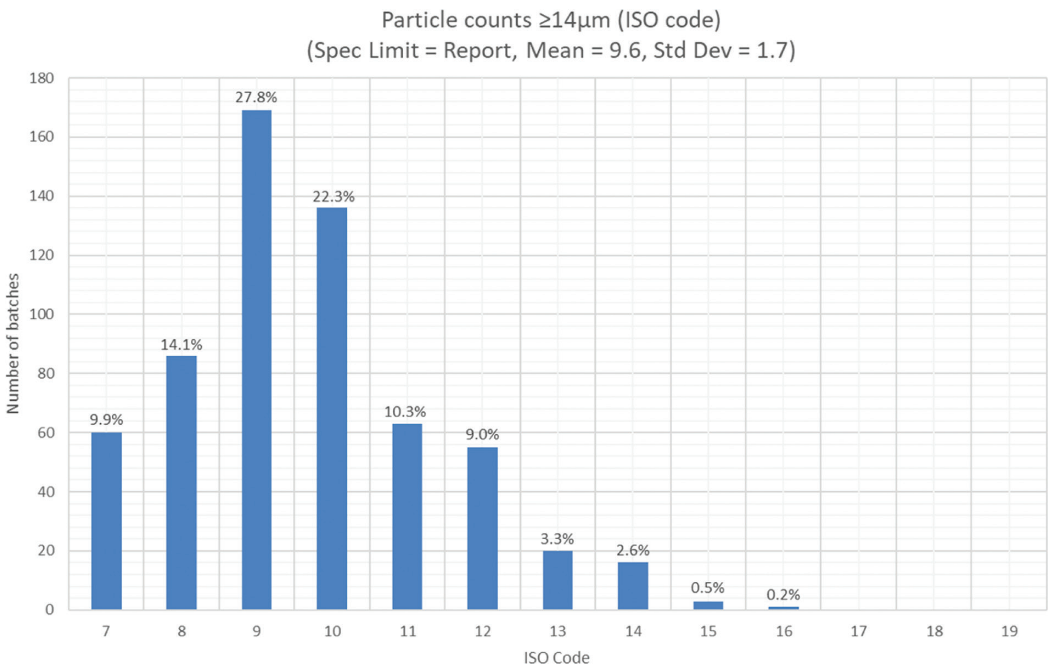

Figure B.70: Particle counts ≥14 µm ISO code (2017)

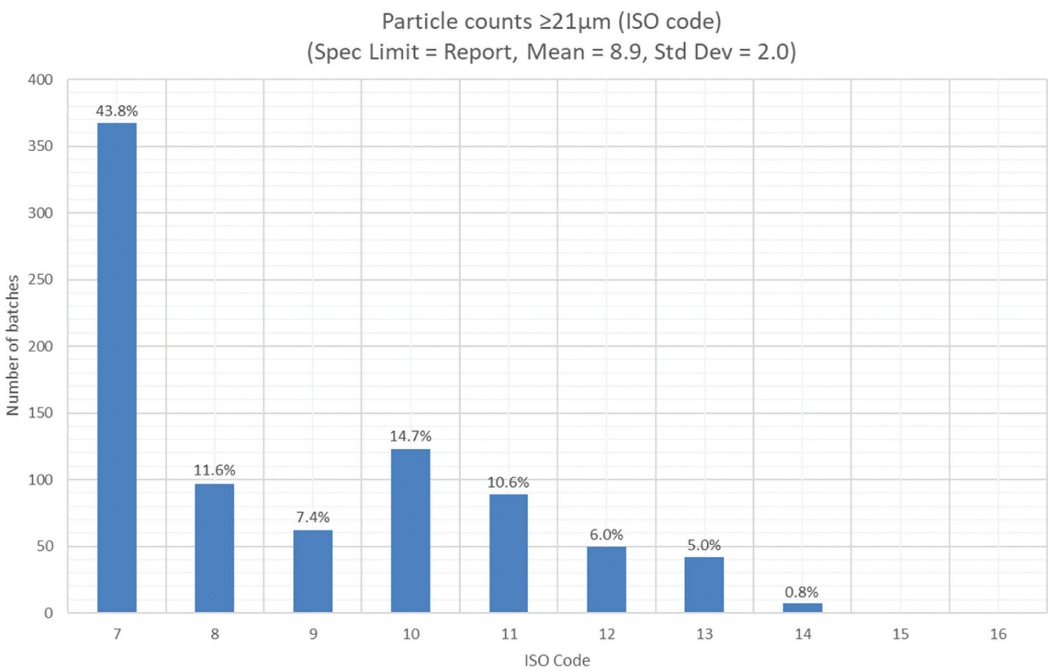

Figure B.71: Particle counts ≥21 µm ISO code (2016)

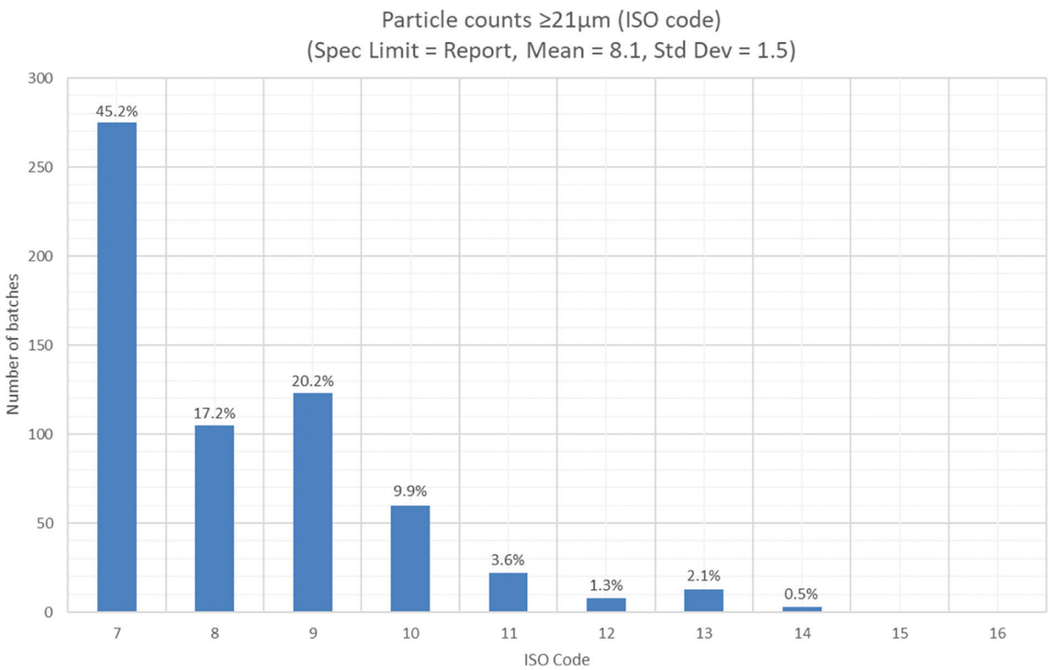

Figure B.72: Particle counts ≥21 µm ISO code (2017)

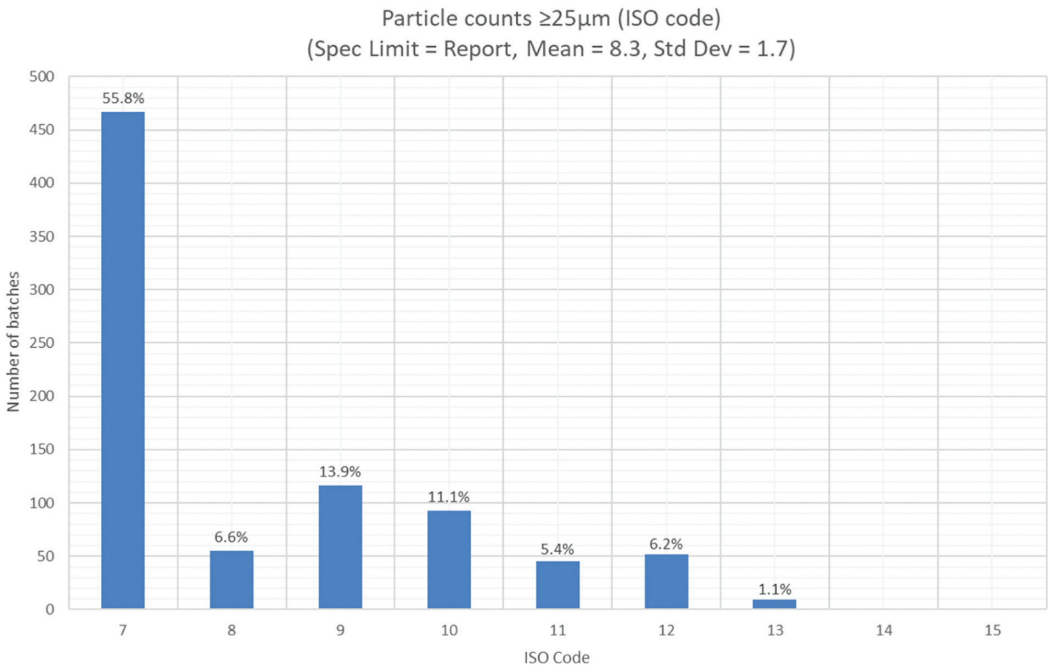

Figure B.73: Particle counts ≥25 µm ISO code (2016)

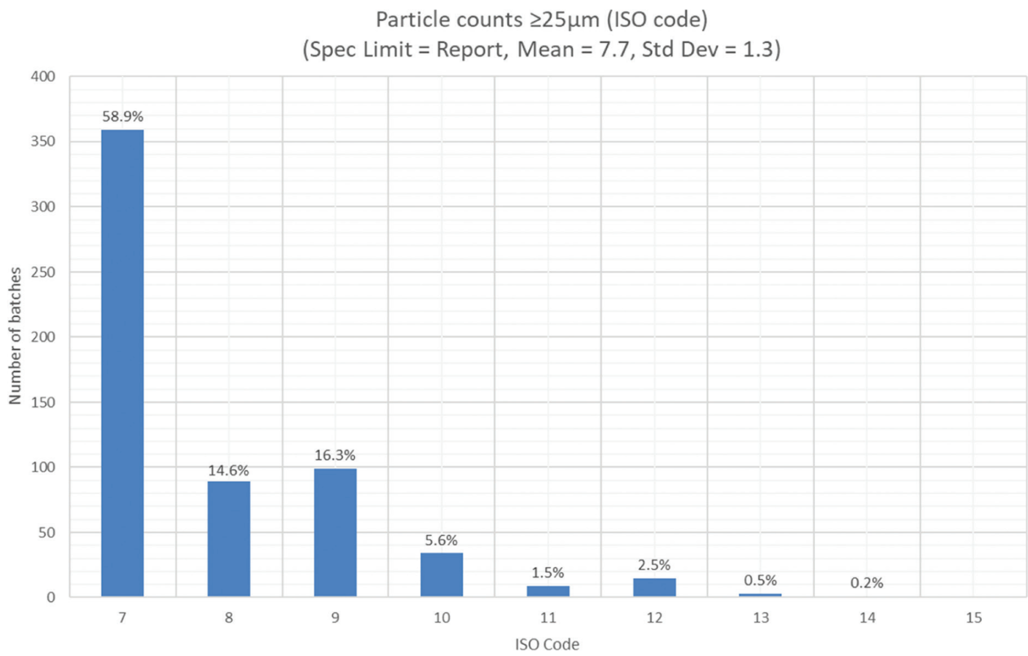

Figure B.74: Particle counts ≥25 µm ISO code (2017)

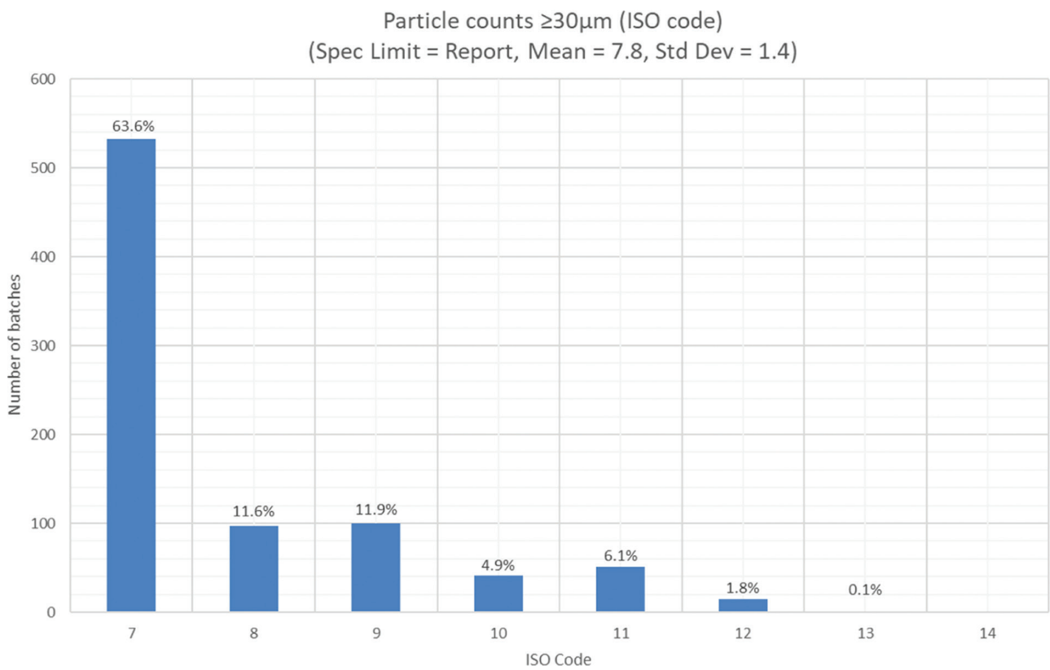

Figure B.75: Particle counts ≥30 µm ISO code (2016)

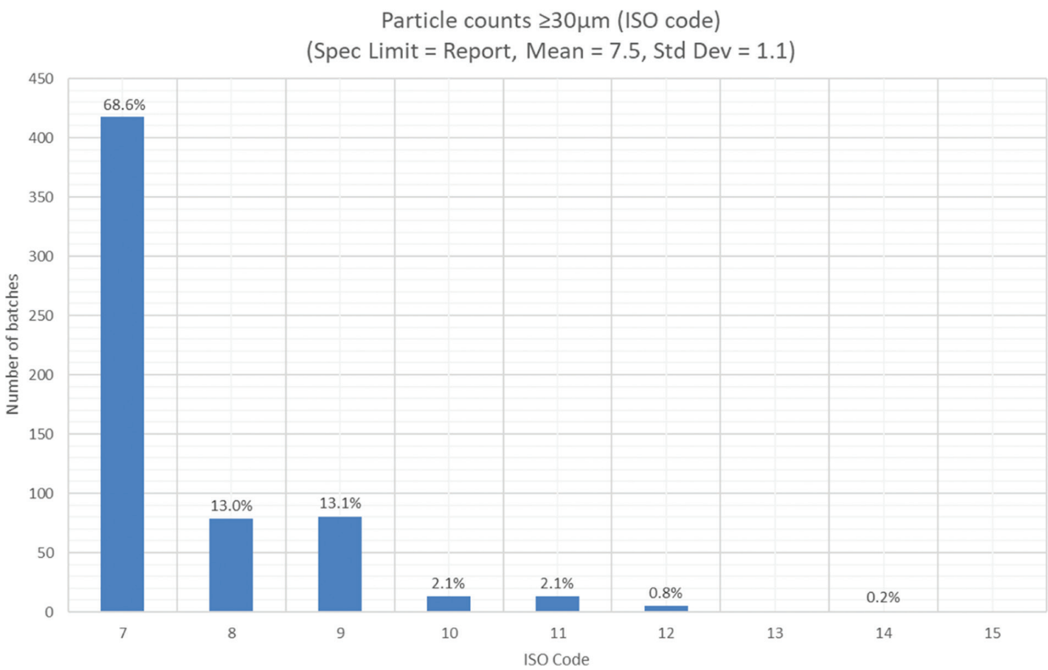

Figure B.76: Particle counts ≥30 µm ISO code (2017)

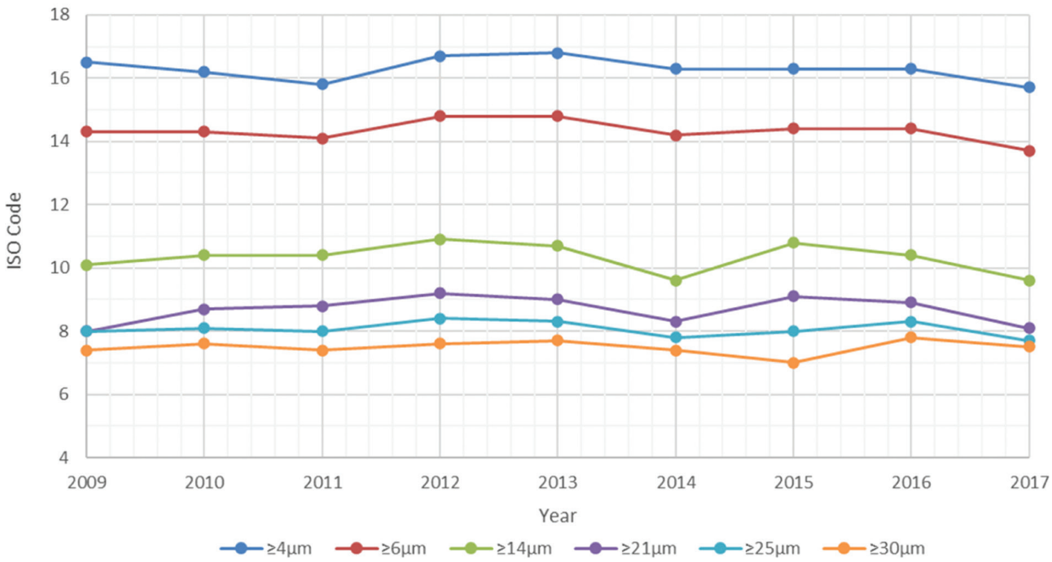

Figure B.77: Particle count trend of the annual mean graph

B.23 NEAR SPECIFICATION LIMIT TREND ANALYSIS

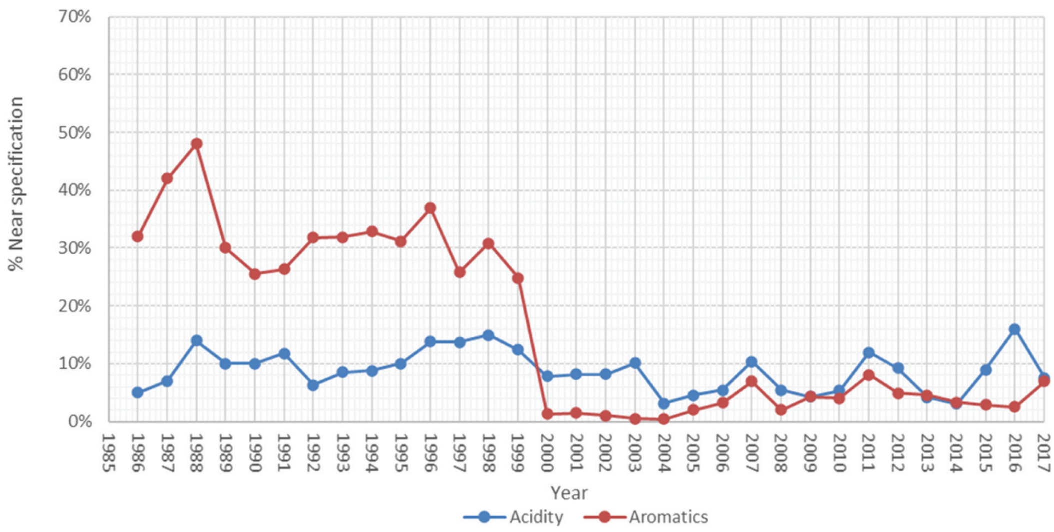

Figure B.78: Near specification trend, acidity and aromatics

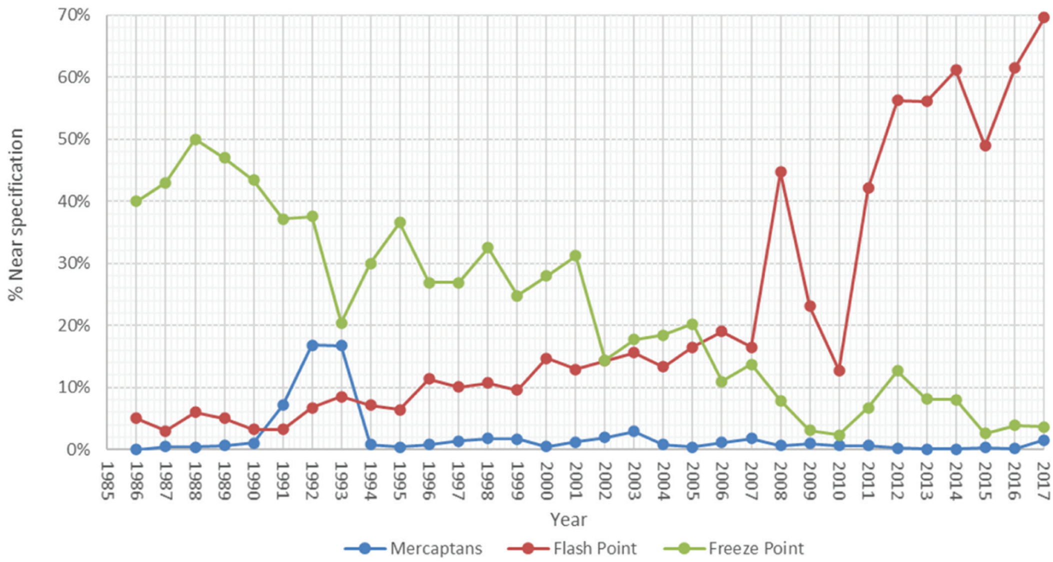

Figure B.79: Near specification trend, mercaptans, flash point and freezing point

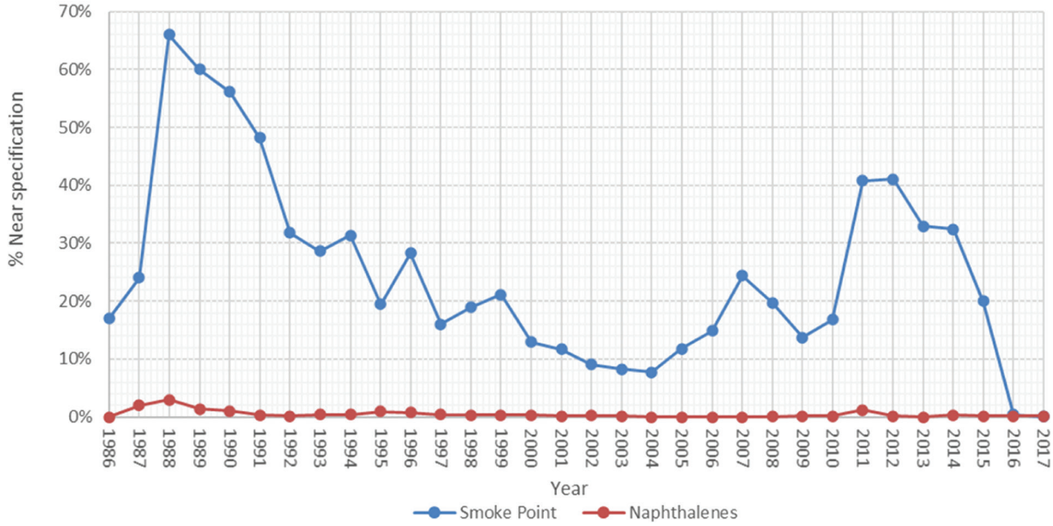

Figure B.80: Near specification trend, smoke point and naphthalenes

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