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CRC/EI Research report

The quality of aviation fuel available in the United Kingdom

Annual survey 2021-2022

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CRC/EI RESEARCH REPORT

THE QUALITY OF AVIATION FUEL AVAILABLE IN THE UNITED KINGDOM ANNUAL SURVEY 2021–2022

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Suggested revisions are invited and should be submitted to the Technical Department, Energy Institute, 61 New Cavendish Street, London W1G 7AR, UK (e: technical@energyinst.org).

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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 2021 and 2022 (data from 2020 omitted due to the small fuel volume supplied as a result of the COVID pandemic). The data for each year are expressed separately, in the form of histograms and mean values, which are graphically compared over the period 1986-2022. This report is the 41st 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[B])[1–27]. This report covers a similar survey for aviation fuel (Jet A-1) supplied during the years 2021 and 2022, including 477 and 840 batches respectively complying with Defence Standard 91-091[28]. Historically, this survey was funded by the UK Ministry of Defence (MoD) in support of its 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 main batches of aviation fuel released during 2021 and 2022. The production of aviation fuel during 2020 was likely to have been very low due to the pandemic, and this survey has not included data from that year. The data have been expressed in the form of histograms and mean values, which are graphically compared over the period of 1986 to 2022. 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 do not give exact details on the number of imports, it is expected that a large proportion of the data contained in this survey are from imported batches. Therefore, the data presented are 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, original equipment manufacturers (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.

B 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 have 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 2021 and 2022. 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, where provided, 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 were recorded. All thermal stability results that were available were reported at 260 °C. The data for electrical conductivity were 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.[29]

2.1 TABULATED DATA

Tables A.1 and A.2 detail the specification limits for each property from Defence Standard 91-091 compared with 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, where available, for each property plotted against year for the period 1986 to 2022.

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 2022

For seven specification properties, Figure B.78 to Figure B.80 show the percentage of batches that have results near the specification limits (results lie within the reproducibility of the method at the specification limit), plotted against year for the period 1986 to 2022. The properties the figures relate to are listed as follows:

– Figure B.78: acidity, aromatics;
– Figure B.79: mercaptan sulfur, flash point, freeze point, and
– 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 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.

3.1 SAMPLE SIZE

In 2021, results for 477 batches were recorded. In 2022, results for 840 batches were recorded. These batches represent 5 494 108 m^3 and 9 061 801 m^3 respectively. In total, this report includes data from approximately 40 000 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 allowing waivers, for various reasons, or due to the data provided having some results unavailable.

3.2 TOTAL ACIDITY

The volume weighted mean value in 2021 and 2022 was 0,0047 and 0,0044 mg KOH/g respectively. The results do not indicate increasing or decreasing trends (Figure B.3). The percentage of batches 'near specification limit' has showed some fluctuation in recent years but there is no obvious trend.

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 15,4 % v/v in 2021 (Figure B.4) and 15,0 % v/v in 2022 (Figure B.5). There appears to be a decreasing trend in mean values; the values for 2021 and 2022 are historically low.

In 2021 and 2022, aromatic content ranged from 3,6 % v/v to 22,6 % v/v with more than 99 % of batches in the range 7 % v/v to 23 % v/v. The percentage of batches 'near specification limit' decreased to 0 % in 2022, the lowest value recorded since records began in 1986.

3.4 TOTAL SULFUR

The volume weighted mean value was 0,035 % m/m (Figure B.7) in 2021, and 0,044 % m/m (Figure B.8) in 2022. There appears to be no apparent trend in recent years. The total sulfur content also appears to show a multimodal distribution.

Defence Standard 91-091 allows several different methods for determining the sulfur content. Some laboratories use methods that can determine the sulfur content to three decimal places, whereas different methods or older equipment only have capablity to report results to two decimal places. The most commonly used test method is IP 336 *Petroleum products – Determination of sulfur content – Energy-dispersive-X-ray fluorescence method*, which is reportable to 0,01 % m/m (with a scope minimum of 0,03 % m/m)[29]. Consequently, results for many batches are reported to two decimal places and those with low sulfur content have been reported as '<0,01 % m/m'. For the purposes of this survey, to remain consistent with previous publications, such results have been recorded as 0,01 % m/m.

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

3.5 MERCAPTAN SULFUR

Mercaptan sulfur was reported for approximately 60 % of batches. Mercaptan sulfur is not required to be reported if the 'doctor' test is negative. Nevertheless, some batches had mercaptan sulfur reported even though the doctor test was negative and these data have been recorded. The volume weighted means were 0,0011 % m/m and 0,0013 % m/m in 2021 and 2022 respectively (Figure B.10 and Figure B.11). The weighted mean values have increased since 2016 with the highest historical result recorded in 2022 (Figure B.12).

Results for a number of batches showed the mercaptan sulfur 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 sulfur (where the doctor test is negative), the true mean value of mercaptan sulfur in jet fuel is likely to be lower than reported here. One result higher than the specification limit was reported; this sample showed a negative doctor test. The result may have been a typing error.

3.6 DISTILLATION

The volume-weighted mean value for initial boiling point (IBP) was 151,3 °C in 2021 and 149,5 °C in 2022 (Figure B.13 and Figure B.14). The mean values in 2021 and 2022 for 10 % recovered were 169,9 °C and 168,1 °C respectively (Figure B.16 and Figure B.17). Fifty per cent recovered results in 2021 and 2022 were both 193,8 °C (Figure B.19 and Figure B.20).

IBP, 10 % and 50 % recovered mean values have shown no significant trends in the last few years.

The 2021 and 2022 weighted mean values for 90 % recovered were 229,7 °C and 234,3 °C respectively (Figure B.22 and B.23). The final boiling point (FBP) weighted means of 251,3 °C and 256,9 °C recorded in 2021 and 2022 (Figure B.25 and Figure B.26) show no consistent trend (Figure B.27).

Aviation turbine fuels containing synthesized hydrocarbons, in accordance with ASTM D7566 *Standard specification for aviation turbine fuel containing synthesized hydrocarbons*[30], have extended requirements (over ASTM D1655 *Standard specification for aviation turbine fuels* [31]

and Defence Standard 91-091) to ensure a sufficient distillation range[C]. The requirements for T50-T10 are a minimum of 15 °C, and for T90-T10 a minimum of 40 °C[D].

There were 22 batches in 2021 and 4 batches in 2022 that were less than 15 for T50-T10. There were 4 batches in 2021 and no batches in 2022 that were less than 40 for T90-T10 (Figures B.28 to B.31).

3.7 FLASH POINT

The volume-weighted mean value for flash point was 42,6 °C in 2021 and 41,8 °C in 2022 (Figure B.32 and Figure B.33). This property has shown a decreasing mean value for many years, but this has been somewhat reversed for 2021 and 2022.

The 'near specification limit' analysis for flash point is shown in Figure B.79. In 2021 and 2022, the proportion of batches that were 'near specification limit' was 43 % and 50 % respectively, which is a large drop from 2018 and 2019, but remains high. A precision study in 2008 led to the reproducibility of IP 170 *Determination of flash point – Abel closed-cup method (ISO 13736:2021)* being changed from 1,5 °C to 3,2 °C. The large changes seen in Figure B.79 are partially due to the change in reproducibility. Flash point appears to be a major constraining factor in jet fuel production for some refineries.

3.8 DENSITY

The volume-weighted mean for density was 798,1 kg/m^3 in 2021 and 797,0 kg/m^3 in 2022 (Figure B.35 and Figure B.36). These values indicate a decreasing trend observed since 2010 (Figure B.37) with the 2022 value equalling the lowest observed. The specification limits are 775 kg/m^3 to 840 kg/m^3.

3.9 FREEZING POINT

The volume-weighted mean value for 2021 was –55,5 °C and in 2022 was –54,9 °C (Figure B.38 and Figure B.39). The mean value appears to show a decreasing trend since the surveys started in 1986.

The percentage of batches 'near specification limit' during 2021 and 2022 was 4,6 % and 3,9 % respectively (Figure B.40). Freezing point no longer appears to be the major constraining factor in jet fuel production it once was for some refineries.

3.10 KINEMATIC VISCOSITY

The volume-weighted mean value in 2021 was 3,70 cSt and was 3,73 cSt in 2022 (Figure B.41 and Figure B.42). There was a decreasing trend in mean viscosity from 2010 to 2015 but an increasing trend since then (Figure B.43).

C It is likely that few 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.

D 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[E], which is approximately equivalent to 5,5 cSt at –20 °C. For 2021 and 2022 there were no batches that exceeded 5,5 cSt, with the maximum result being 5,322 cSt.

3.11 SPECIFIC ENERGY

The volume-weighted means were 43,30 MJ/kg and 43,32 MJ/kg in 2021 and 2022 respectively. There has been an increasing trend in the mean value since 2010 (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 means for 2021 and 2022 were 24,3 mm and 24,6 mm respectively (Figure B.47 and B.48). The smoke point specification limit changed from 19 mm to 18 mm minimum at the start of 2017. Previous surveys showed an unusual distribution with regard to the high percentage of results at 25 mm, which may have been linked to the specification requirement for the measurement of naphthalenes when the smoke point is less than 25 mm. This is less apparent in recent surveys and may be linked to increased use of the automated smoke point methodology.

There appears to be an increasing trend in the volume-weighted mean values since 2010 (Figure B.49). The change in 'near specification' results from 2016 onwards 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. Some naphthalenes results were reported even though not required due to the smoke point result.

The means for 2021 and 2022 were 1,37 % vol and 1,24 % vol respectively (Figure B.50 and B.51). There appears to be 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 of all the batches.

E 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.

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 2021 and 2022 mean values were 0,87 mg/100 ml and 0,97 mg/100 ml respectively, as shown in Figure B.53 and Figure 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 2021 mean microseparometer (MSEP®) value was 91,4, which is similar to the previous few years (Figure B.56). The 2022 mean MSEP® has a value of 92,8 (Figure B.57).

The Defence Standard 91-091 limit for MSEP® rating is a minimum of 85 without SDA, or 70 with SDA due to the oversensitivity of the test method to SDA. No batches had results below 70.

3.16 PARTICULATE CONTAMINATION

This requirement for Defence Standard 91-091 has a maximum limit of 1 mg/l, and no batches in 2021 and 2022 had a result above this limit (Figure B.59 and Figure B.60).

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 minimal variation in the mean values (Figure B.61).

3.17 SAYBOLT COLOUR

Saybolt colour is a relatively new requirement for Defence Standard 91-091. The 2021 volume-weighted mean value was 27,7 (Figure B.62). The 2022 volume-weighted mean value was 27,9 (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[F,32]. Histograms show the distribution of ISO codes for ≥4 µm, ≥6 µm, ≥14 µm, ≥21 µm, ≥25 µm and ≥30 µm channels (Figure B.65 to Figure B.76). For low particle counts (and low ISO

F 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.

codes) repeatability is poor and many laboratories 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 for the period 2009 to 2022. The mean values show no particular trends.

3.19 LUBRICITY

For batches containing more than 95 % hydroprocessed material, of which at least 20 % is severely hydroprocessed, Ball-on-Cylinder Lubricity Evaluator (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.[G]

Due to the very small number of results recorded, graphical representations are not provided. However, the minimum, maximum and mean results are recorded in Table A.1 and Table A.2. Three lubricity results were reported in 2021 and 17 results reported in 2022. It was not clear from the data supplied if the refining processes of these fuels required lubricity testing to be carried out.

3.20 NEAR SPECIFICATION TRENDS

Figure B.78 to Figure B.80 show the percentage of batches with test results near the specification limit, plotted against year, for seven specification properties.

The property with the highest percentage of batches with results near the specification limit in 2021 and 2022 was flash point (43 % and 50 %). Smoke point batches near specification limit reduced dramatically from 2016 due to test method and specification limit changes.

G It should be noted that some of the data supplied for this survey were not in the form of test certificates but supplied in spreadsheet format. Whilst electronic data do not provide all of the data found on the main batch test certificates, there is no suggestion that the original certificate did not contain the correct information or that the fuel did not comply with the requirements of Defence Standard 91-091.

4 SUMMARY OF CHANGES AND TRENDS

4.1 TREND DATA

Table 1: Properties showing increasing or decreasing trends

Properties where there is a rising trend	Properties where there is a decreasing trend
Smoke point mean value (increasing since 2010)	Freezing point mean value (decreasing trend since 1986)
Mercaptan sulfur mean value (increasing since 2016)	Aromatics mean value (decreasing since 1986)
Saybolt colour mean value (increasing since 2007)	
Specific energy mean value (increasing trend since 2010)	

4.2 SIGNIFICANT CHANGES

Table 2: Significant changes in mean values for 2021 and 2022

Property	Change
Mercaptan sulfur	2021 and 2022 showed the highest value since records began in 1986
Density	2022 showed the joint highest value since records began in 1986
Aromatics	2021 value shows a drop of 1,7 % v/v from 2019, and the 2022 value is historically low
Smoke point	2022 is the highest value since records began
Sulfur	2021 value is historically low
Specific energy	2021 and 2022 showed the highest values since records began in 1986

5 REFERENCES

The first list is ordered by reference number as used in this report. The second list contains the same references, ordered by publisher.

5.1 REFERENCES ORDERED BY NUMBER

[1] Various Materials Quality Assurance Directorate (MQAD) and Harefield Annual Fuel Surveys 1974 1986

[2] DQA/TS Materials Centre Report No. 361, March 1987

[3] DQA/TS Technical Report No. 88/2, May 1988

[4] DQA/TS Technical Report No. 89/8, November 1989

[5] DQA/TS Technical Report No. 91/4, March 1991

[6] DQA/TS Technical Report No. 91/10, November 1991

[7] QATS FL Division Technical Paper FLT/1/93, March 1993

[8] QATS FL Division Technical Paper FLT/3/93, June 1993

[9] FVS FL Division Technical Paper DRA/FVS/FL/TR94002/1, September 1994

[10] LS FL Division Technical Paper DRA/LS/LSF4/TR95004, June 1995

[11] LS FL Division Technical Paper DRA/LS4/TR96/044/1, July 1996

[12] SMC FL Division Technical Paper DERA/SMC/SM1/TR970039, May 1997

[13] MSS Technical Report DERA/MSS1/TR980069/1.0, May 1998

[14] MSS Technical Report DERA/MSS/MSMA1/TR990400/1.0, August 1999

[15] MSS Technical Report DERA/MSS/MSMA3/CR001238, June 2000

[16] FST Technical Report DERA/FST/CET/TR010603, June 2001

[17] FST Technical Report QinetiQ/FST/CR023267, May 2002

[18] FST Technical Report QinetiQ/FST/CR032630, June 2003

[19] FST Technical Report QinetiQ/FST/TR042832, June 2004

[20] FST Technical Report QinetiQ/FST/ TR050276, June 2005

[21] FST Technical Report QinetiQ/FST/ TR0601360, June 2006

[22] Technical Report QINETIQ/S&DU/T&P/E&M/TR0701148, June 2007

[23] Technical Report QINETIQ/08/01656, June 2008

[24] Technical Report QINETIQ/09/01120, December 2009

[25] *The quality of aviation fuel available in the United Kingdom annual surveys 2009 to 2015.* CRC project No. AV-18-14, October 2019

[26] *The quality of aviation fuel available in the United Kingdom annual surveys 2016 to 2017.* CRC project No. AV-18-19, December 2022

[27] *The quality of aviation fuel available in the United Kingdom annual survey 2018–2019.* EI 3585 & CRC project AV-18-18/19, March 2025

[28] Specification Defence Standard 91-091 *Turbine fuel, aviation kerosine type, Jet A-1, NATO code: F-35, JSD: AVTUR.* Issued by UK Defence Standardization, Kentigern House, 65 Brown Street, Glasgow G2 8EX

[29] IP 336 *Petroleum products – Determination of sulfur content – Energy-dispersive-X-ray fluorescence method*

[30] ASTM D7566 *Standard specification for aviation turbine fuel containing synthesized hydrocarbons*

[31] ASTM D1655 *Standard specification for aviation turbine fuels*

[32] BS ISO 4406 *Hydraulic fluid power – fluids – Method for coding the level of contamination by solid particles*

5.2 REFERENCES ORDERED BY PUBLISHER

ASTM International – https://www.astm.org/

ASTM D1655 *Standard specification for aviation turbine fuels*

ASTM D7566 *Standard specification for aviation turbine fuel containing synthesized hydrocarbons*

British Standards Institution (BSI) – https://www.bsigroup.com

BS ISO 4406 *Hydraulic fluid power – Fluids – Method for coding the level of contamination by solid particles*

Coordinating Research Council (CRC) – https://crcao.org/

The quality of aviation fuel available in the United Kingdom annual surveys 2009 to 2015, CRC Project No. AV-18-14, October 2019

The quality of aviation fuel available in the United Kingdom annual surveys 2016 to 2017, CRC Project No. AV-18-19, December 2022

The quality of aviation fuel available in the United Kingdom annual survey 2018–2019, EI 3585 and CRC Project AV-18-18/19, March 2025

Energy Institute (EI) – https://www.energyinst.org/

IP 156 *Determination of hydrocarbon types in petroleum products – Fluorescent indicator adsorption method*

IP 336 *Petroleum products – Determination of sulfur content – Energy-dispersive X-ray fluorescence method*

IP 436 *Determination of aromatic hydrocarbon types in aviation fuels and petroleum distillates – High performance liquid chromatography method with refractive index detection*

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FST Technical Report QinetiQ/FST/CR023267, May 2002

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FST Technical Report QinetiQ/FST/TR042832, June 2004

FST Technical Report QinetiQ/FST/TR050276, June 2005

FST Technical Report QinetiQ/FST/TR0601360, June 2006

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Technical Report QinetiQ/09/01120, December 2009

UK Defence Standardization – https://www.gov.uk/guidance/uk-defence-standardization

Defence Standard 91-091 *Turbine fuel, aviation kerosine type, Jet A-1, NATO code: F-35, JSD: AVTUR*

APPENDIX A
RESULTS SUMMARIES

A.1 2021 DATA FROM 477 BATCHES OF JET FUEL REPRESENTING 5 494 108 M³

Table A.1: Minima and maxima for 2021, data and specification limits

Method	Def Stan 91-091 Specification limits		Results summary 2021		
	Min.	Max.	Min.	Max.	Mean
Total acidity, mg KOH/g	-	0,015	0,000	0,015	0,005
Aromatics, % volume	-	25,0[H]	5,5	22,6	15,4
Total sulfur, % mass	-	0,30	0,001	0,180	0,035
Mercaptan sulfur, % mass	-	0,0030	0,0003	0,0030	0,0011
Distillation IBP, °C	Report		140,7	172,1	151,3
10 % recovery, °C	-	205,0	160,3	189,1	169,9
50 % recovery, °C	Report		177,6	217,4	193,8
90 % recovery, °C	Report		204,1	272,1	229,7
FBP, °C	-	300,0	226,8	283,9	251,3
Flash point, °C	38,0	-	38,0	57,5	42,6
Density @ 15 °C, kg/m³	775,0	840,0	784,0	820,8	798,1
Freezing point, °C	-	–47,0	–71,0	–47,1	–55,5
Viscosity @ –20 °C, mm²/s	-	8,00	2,51	5,32	3,70
Specific energy, net MJ/kg	42,80	-	43,03	43,67	43,30
Smoke point, mm	18,0	-	19,3	33,7	24,3
Naphthalenes, % volume	-	3,00	0,17	2,98	1,37
Existent gum, mg/100 ml	-	7	0	4	0,44
MSEP®	85 (70 with SDA)	-	70	100	91
BOCLE, mm	-	0,85	0,61	0,74	0,68
Particulate, mg/l	-	1,0	0,00	0,93	0,20
Colour	Report		16	30	27,7
Particle count,					
≥4 µm	-	19	11	20	15,5
≥6 µm	-	17	9	19	14,0
≥14 µm	-	14	7	15	10,0
≥21 µm	-	Report	7	14	8,7
≥25 µm	-	Report	7	13	8,2
≥30 µm	-	13	7	13	7,8

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

A.2 2022 DATA FROM 840 BATCHES OF JET FUEL REPRESENTING 9 061 801 M³

Table A.2: Minima and maxima for 2022 data and specification limits

Method	Def Stan 91-091 Specification limits		Results summary 2022		
	Min.	Max.	Min.	Max.	Mean
Total acidity, mg KOH/g	-	0,015	0,000	0,015	0,004
Aromatics, % volume	-	25,0[J]	3,6	21,8	15,0
Total sulfur, % mass	-	0,30	0,000	0,250	0,044
Mercaptan sulfur, % mass	-	0,0030	0,0003	0,0050	0,0013
Distillation IBP, °C	Report		138,9	167,0	149,5
10 % recovery, °C	-	205,0	149,6	186,2	168,1
50 % recovery, °C	Report		174,8	211,2	193,8
90 % recovery, °C	Report		211,0	267,9	234,3
FBP, °C	-	300,0	232,1	282,8	256,8
Flash point, °C	38,0	-	38,0	55,0	41,8
Density @ 15 °C, kg/m³	775,0	840,0	778,6	818,9	797,0
Freezing point, °C	-	–47,0	–65,9	–48,2	–54,9
Viscosity @ –20 °C, mm²/s	-	8,00	2,68	5,313	3,74
Specific energy, net MJ/kg	42,80	-	43,09	43,68	43,32
Smoke point, mm	18,0	-	20,0	32,2	24,6
Naphthalenes, % volume	-	3,00	0,16	2,79	1,24
Existent gum, mg/100 ml	-	7	0	5	0,97
MSEP®	85 (70 with SDA)	-	70	100	93
BOCLE, mm	-	0,85	0,57	0,75	0,67
Particulate, mg/l	-	1,0	0,00	0,81	0,19
Colour	Report		13	30	27,9
ISO code,					
≥4 µm	-	19	9	22	15,9
≥6 µm	-	17	7	21	13,9
≥14µm	-	14	7	16	10,2
≥21 µm	-	Report	7	14	8,8
≥25 µm	-	Report	7	13	8,2
≥30 µm	-	13	7	13	7,8

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

APPENDIX B
FIGURES

B.1 TOTAL ACIDITY

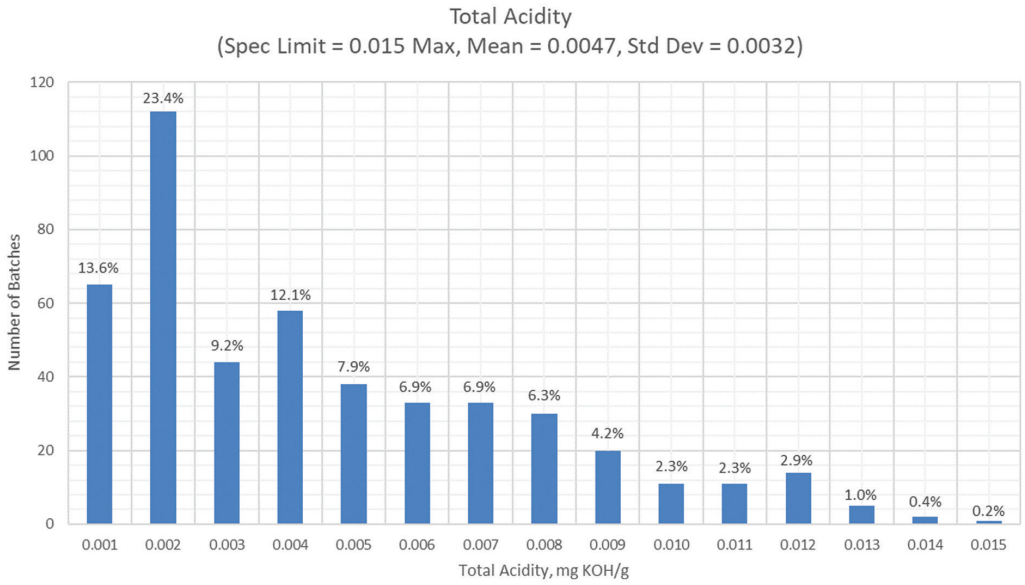


Figure B.1: Total acidity histogram (2021)

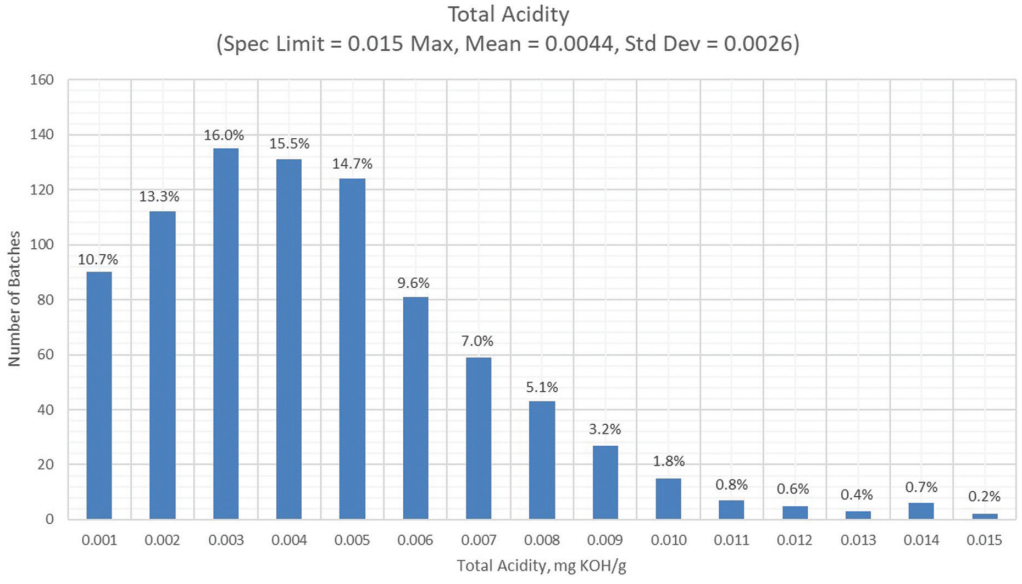


Figure B.2: Total acidity histogram (2022)

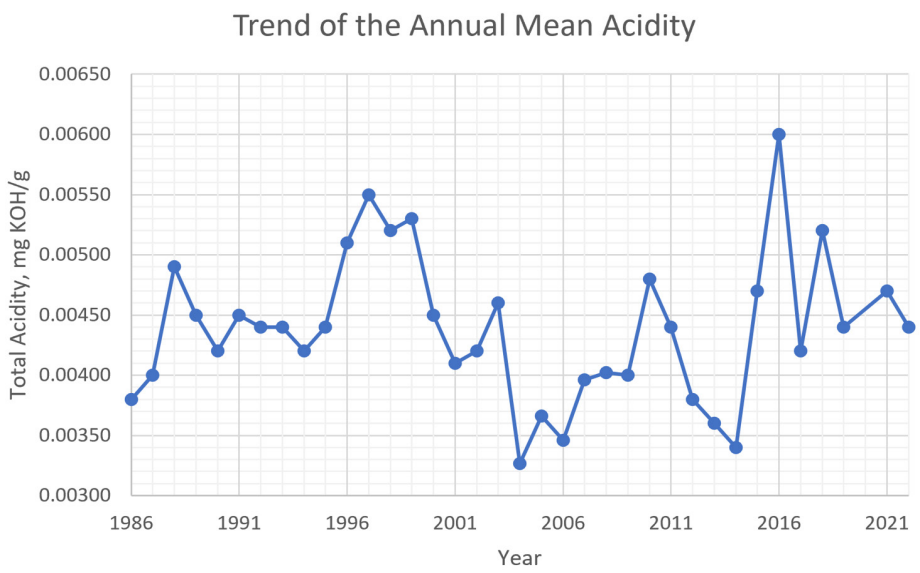


Figure B.3: Total acidity trend graph

B.2 AROMATICS

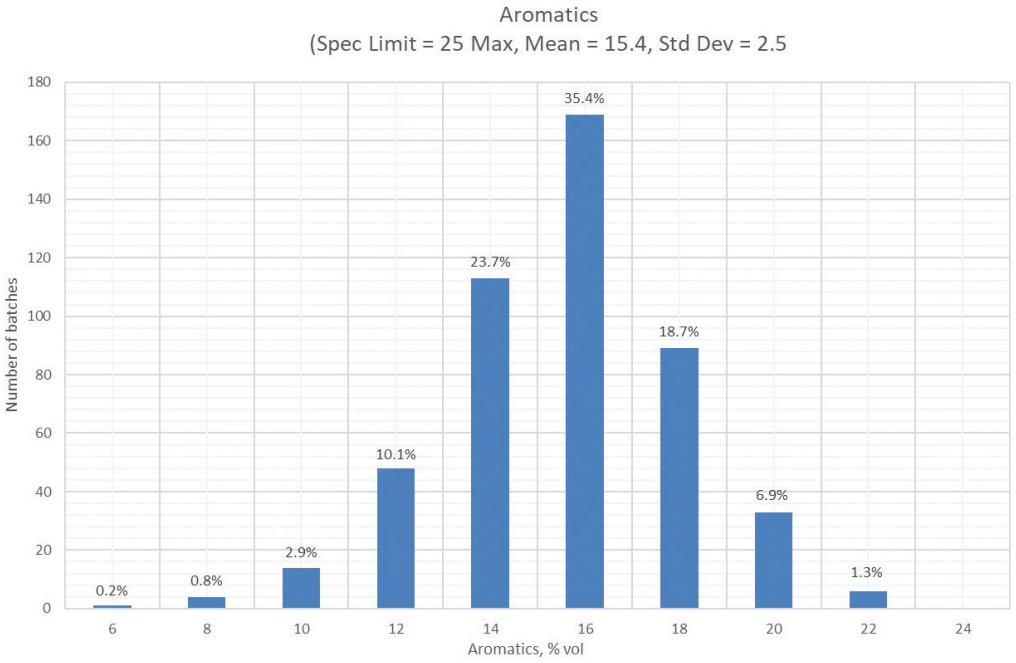


Figure B.4: Aromatics histogram (2021)

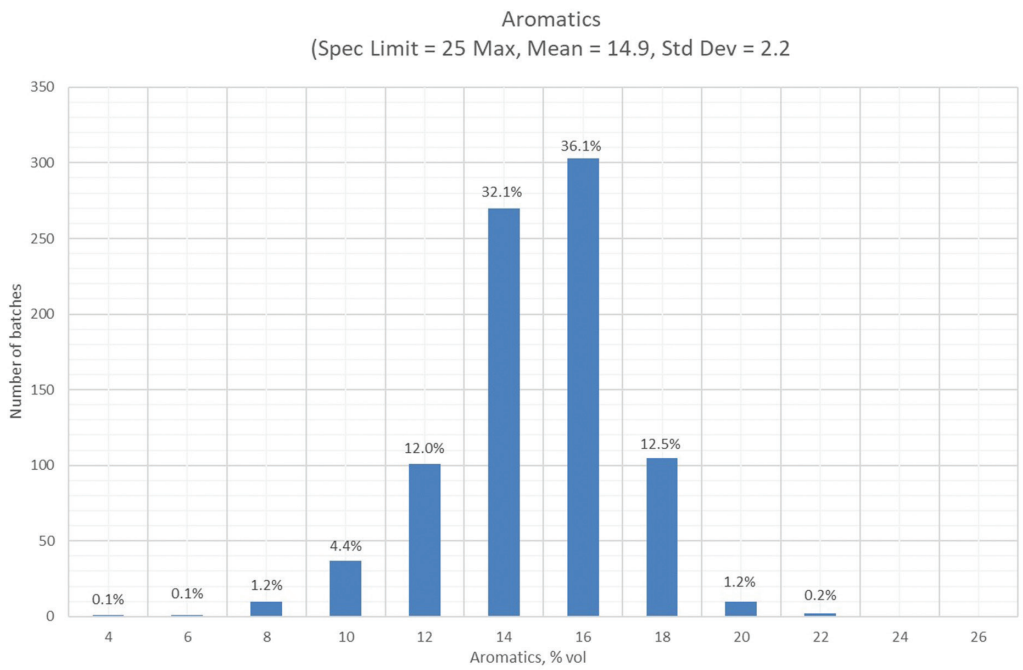


Figure B.5: Aromatics histogram (2022)

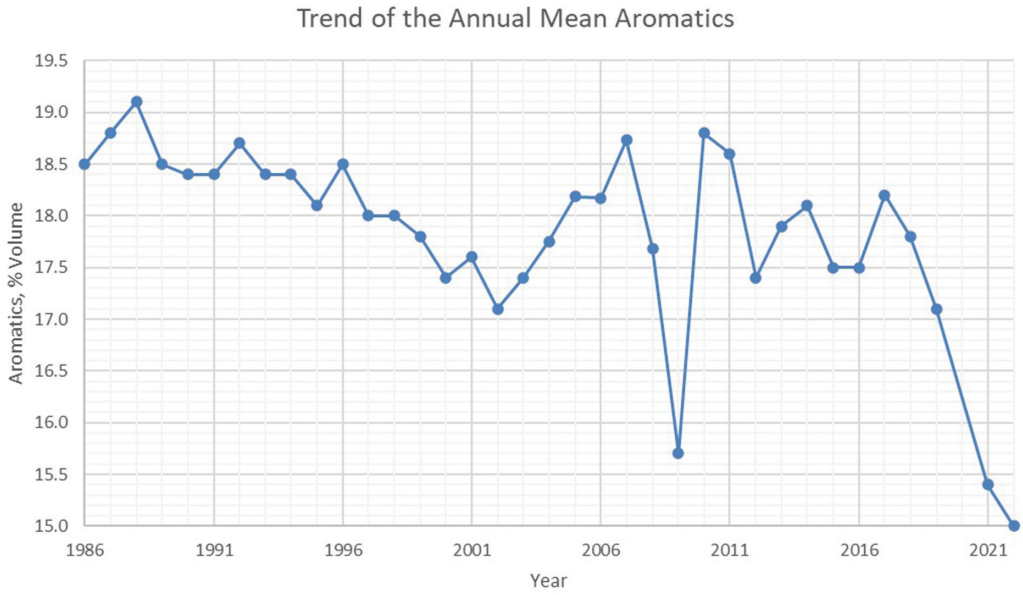


Figure B.6: Aromatics trend graph

B.3 TOTAL SULFUR

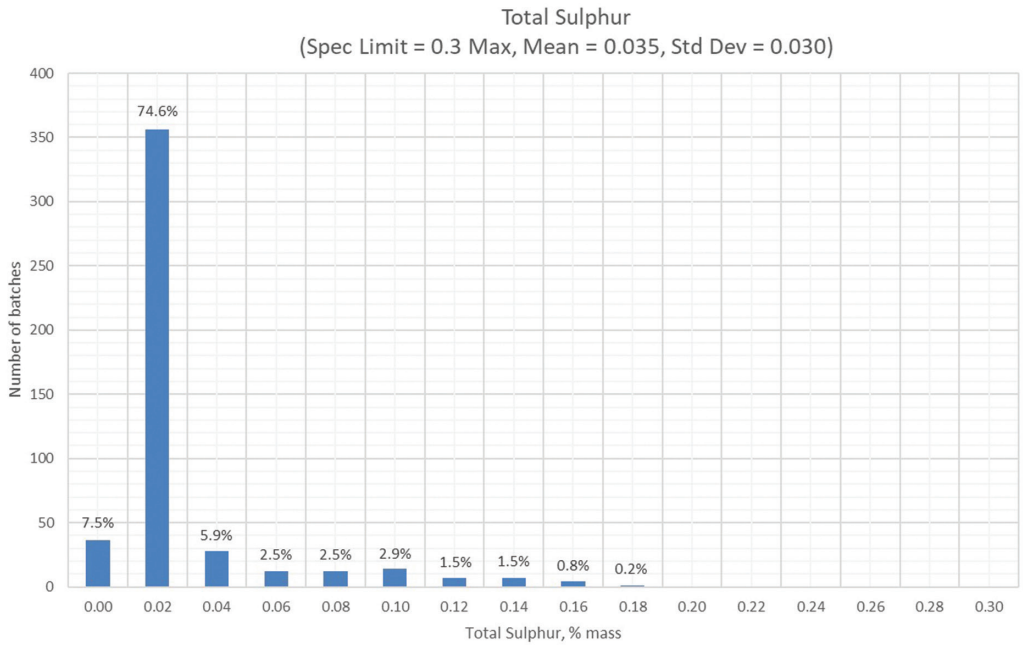


Figure B.7: Total sulfur histogram (2021)

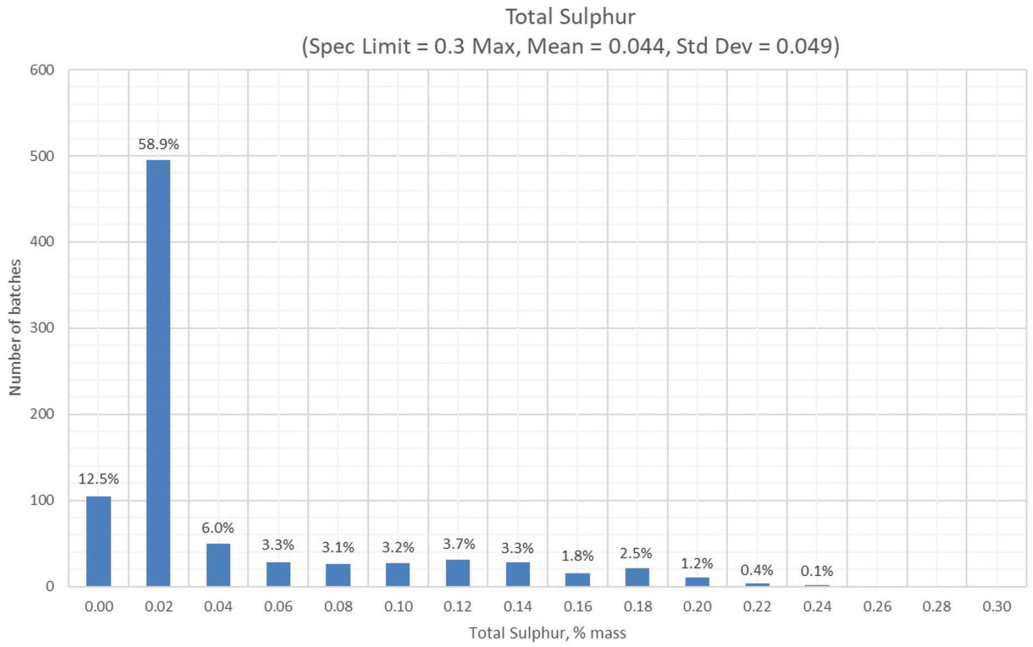


Figure B.8: Total sulfur histogram (2022)

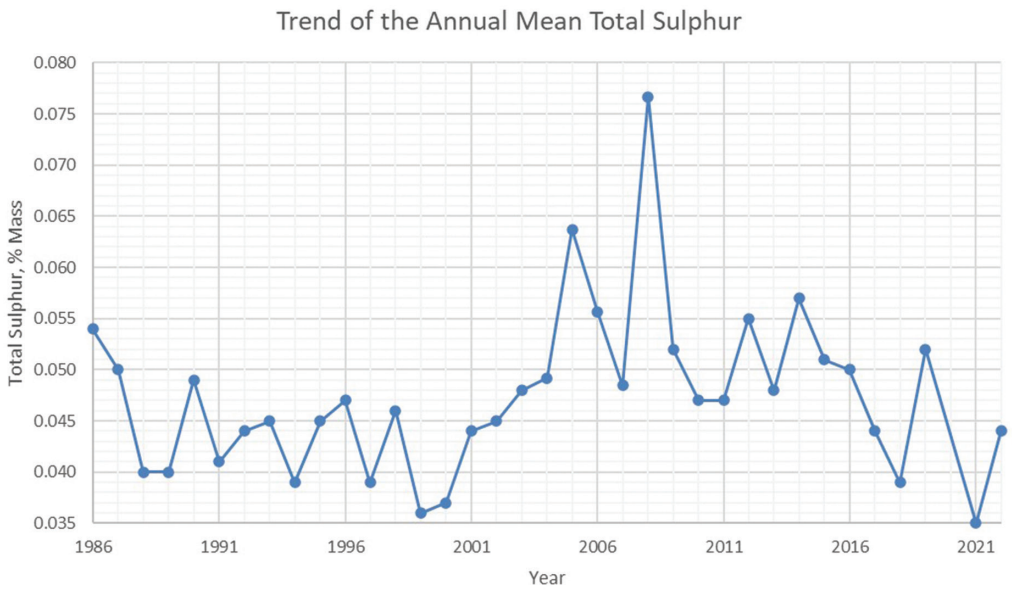


Figure B.9: Total sulfur trend graph

B.4 MERCAPTAN SULFUR

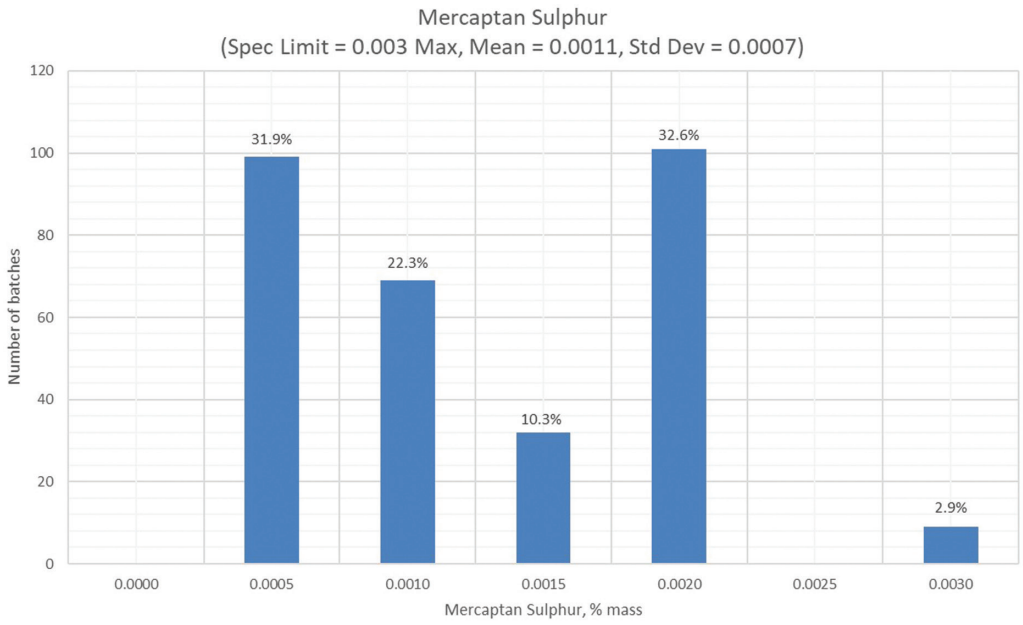


Figure B.10: Mercaptan sulfur histogram (2021)

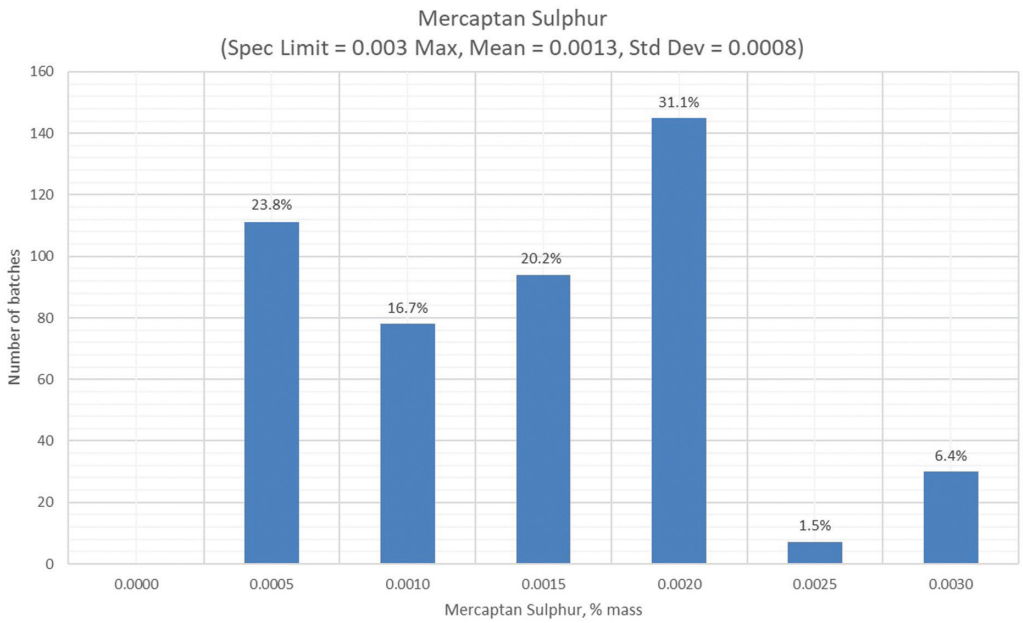


Figure B.11: Mercaptan sulfur histogram (2022)

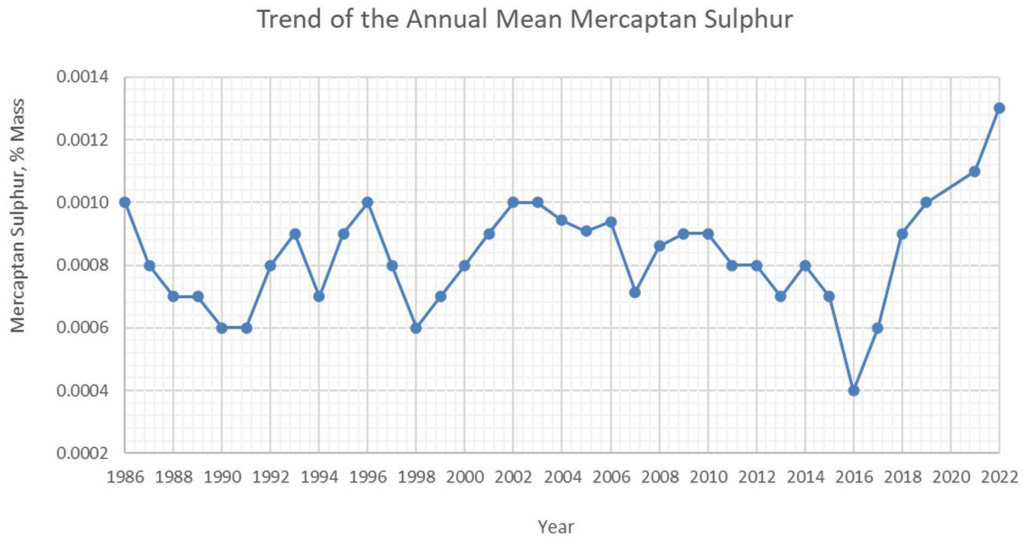


Figure B.12: Mercaptan sulfur trend graph

B.5 DISTILLATION IBP

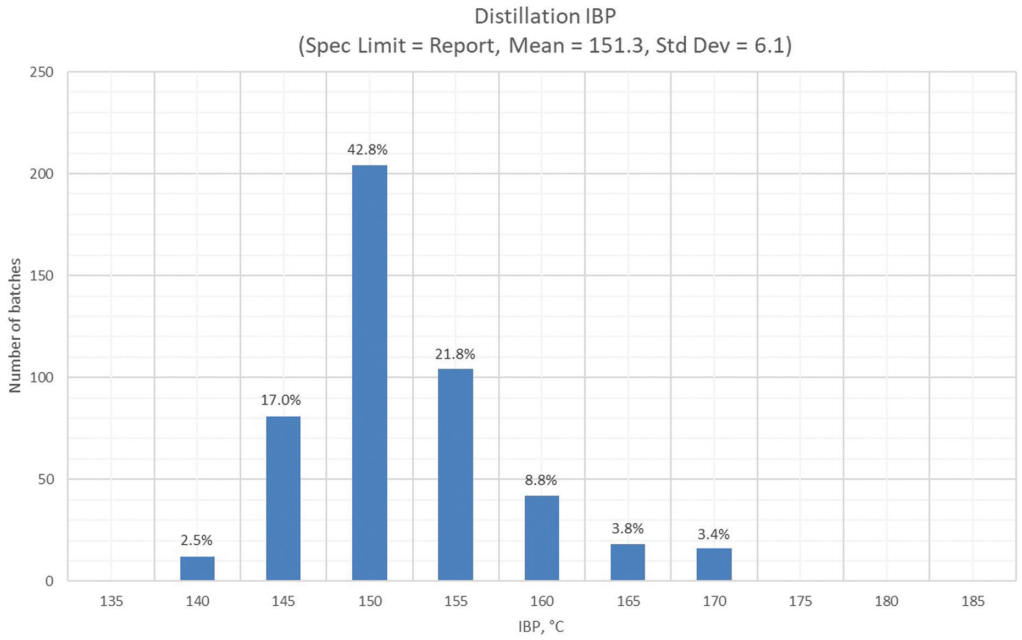


Figure B.13: Distillation IBP histogram (2021)

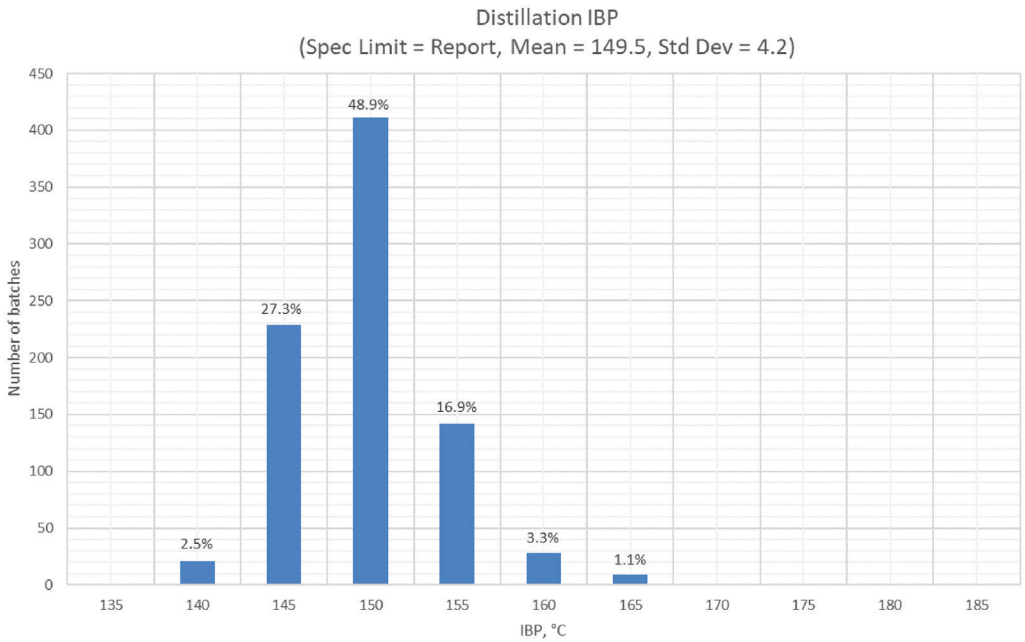


Figure B.14: Distillation IBP histogram (2022)

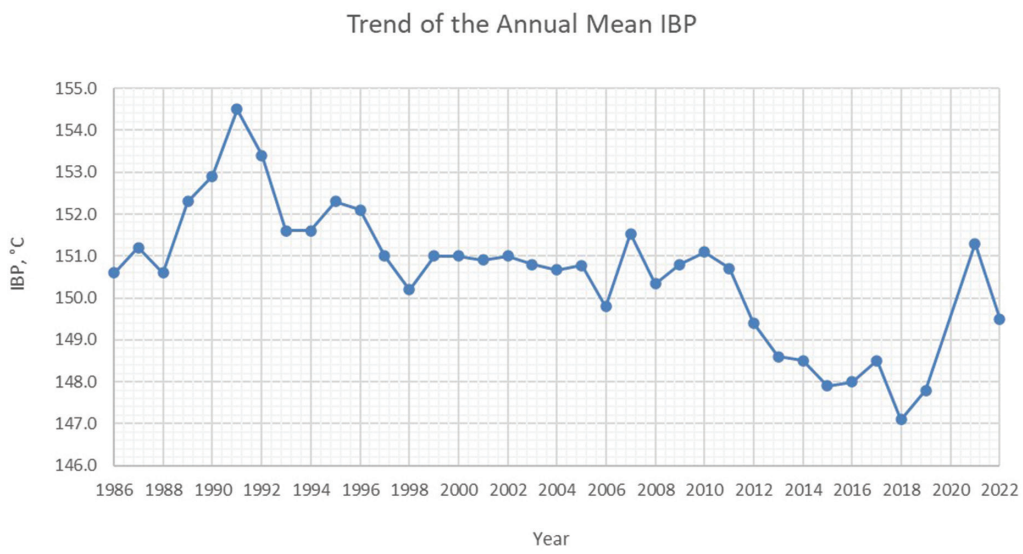


Figure B.15: Distillation IBP trend graph

B.6 DISTILLATION 10 % RECOVERY

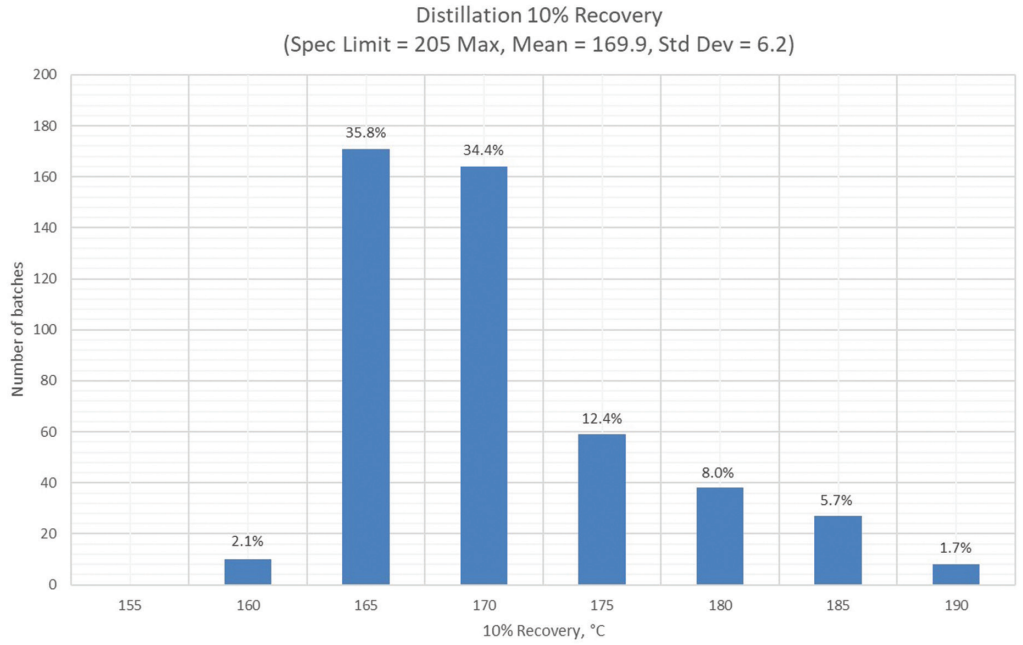


Figure B.16: Distillation 10 % recovery histogram (2021)

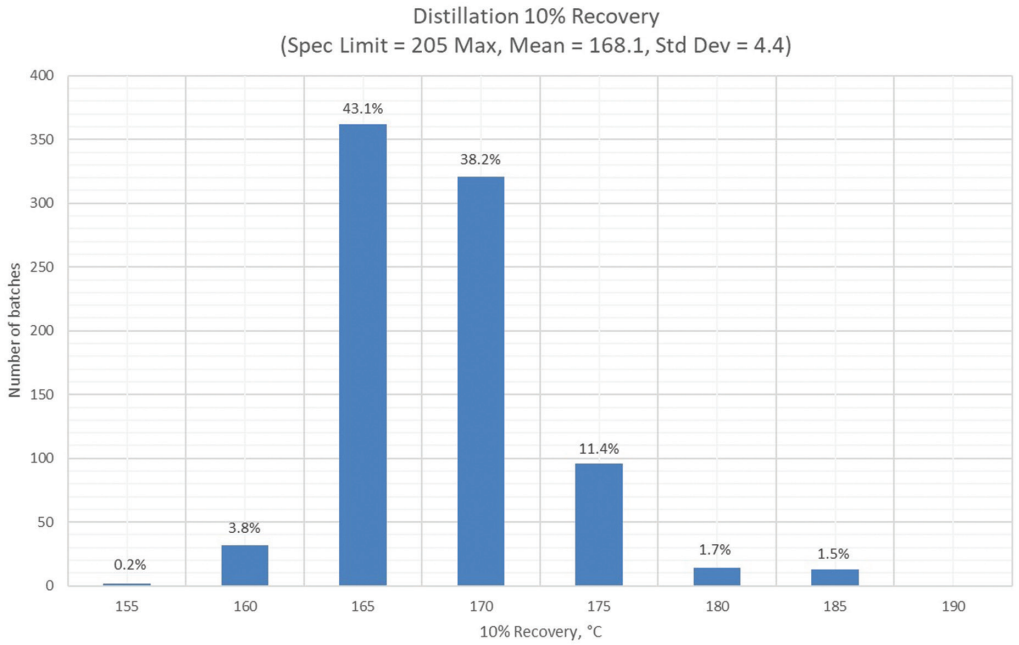


Figure B.17: Distillation 10 % recovery histogram (2022)

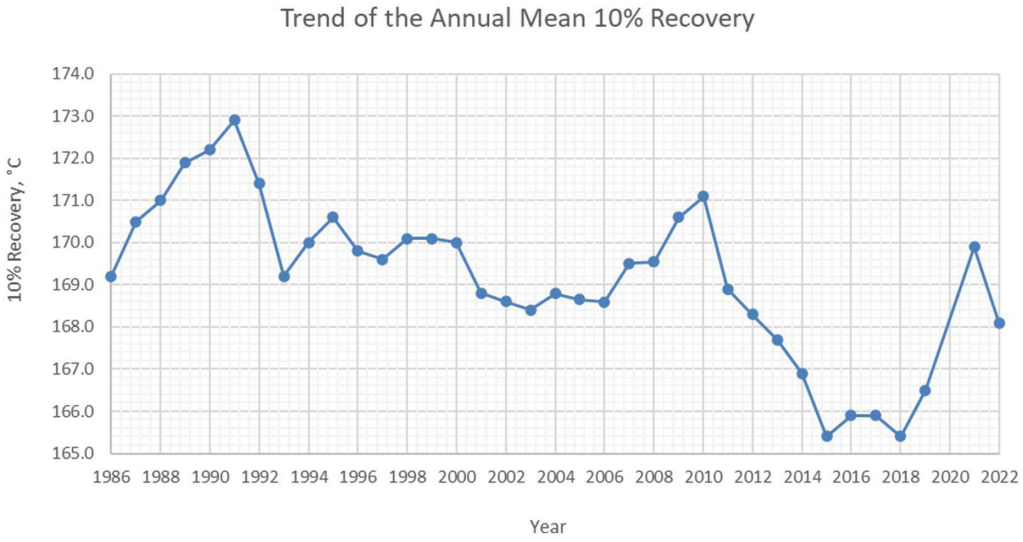


Figure B.18: Distillation 10 % recovery trend graph

B.7 DISTILLATION 50 % RECOVERY

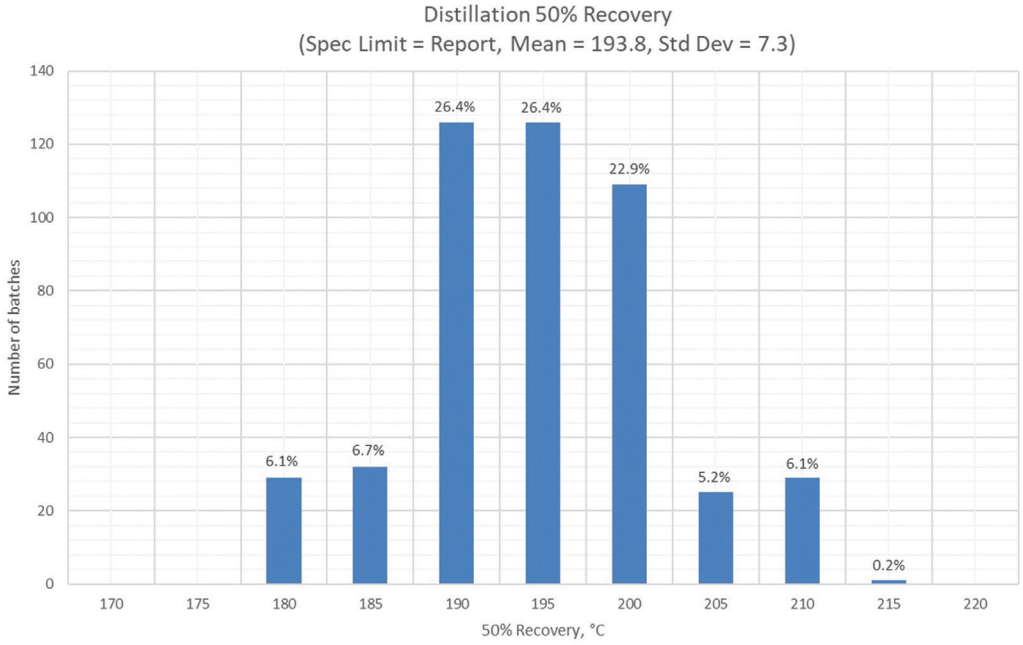


Figure B.19: Distillation 50 % recovery histogram (2021)

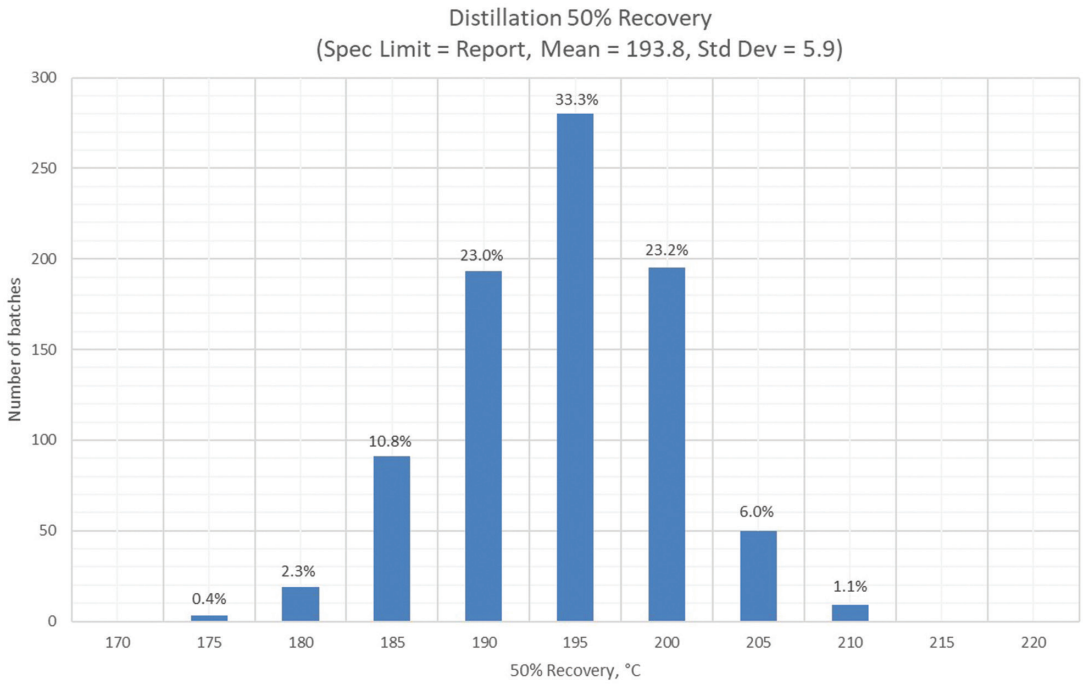


Figure B.20: Distillation 50 % recovery histogram (2022)

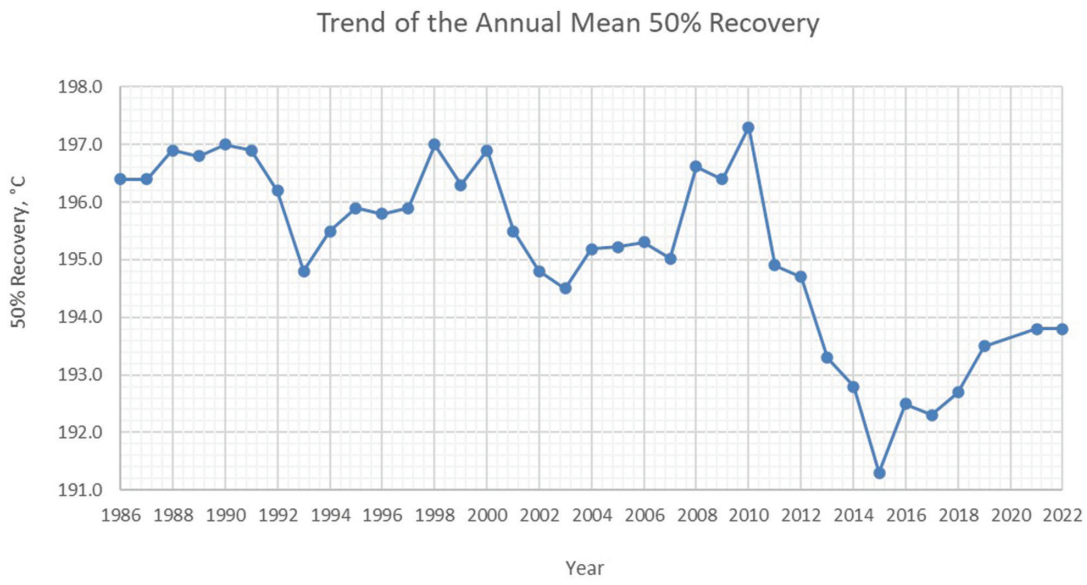


Figure B.21: Distillation 50 % recovery trend graph

B.8 DISTILLATION 90 % RECOVERY

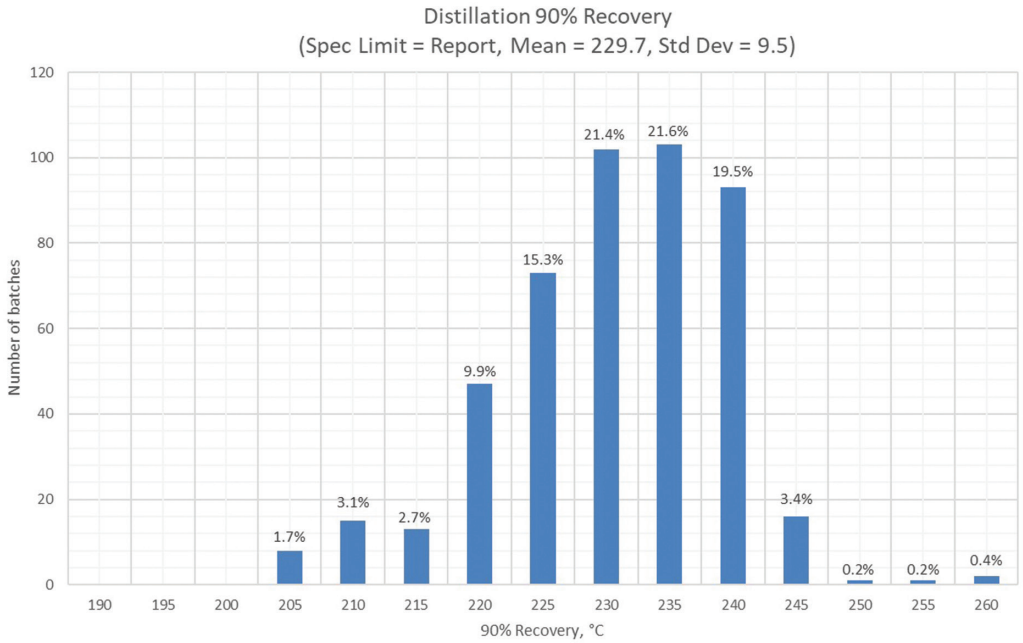


Figure B.22: Distillation 90 % recovery histogram (2021)

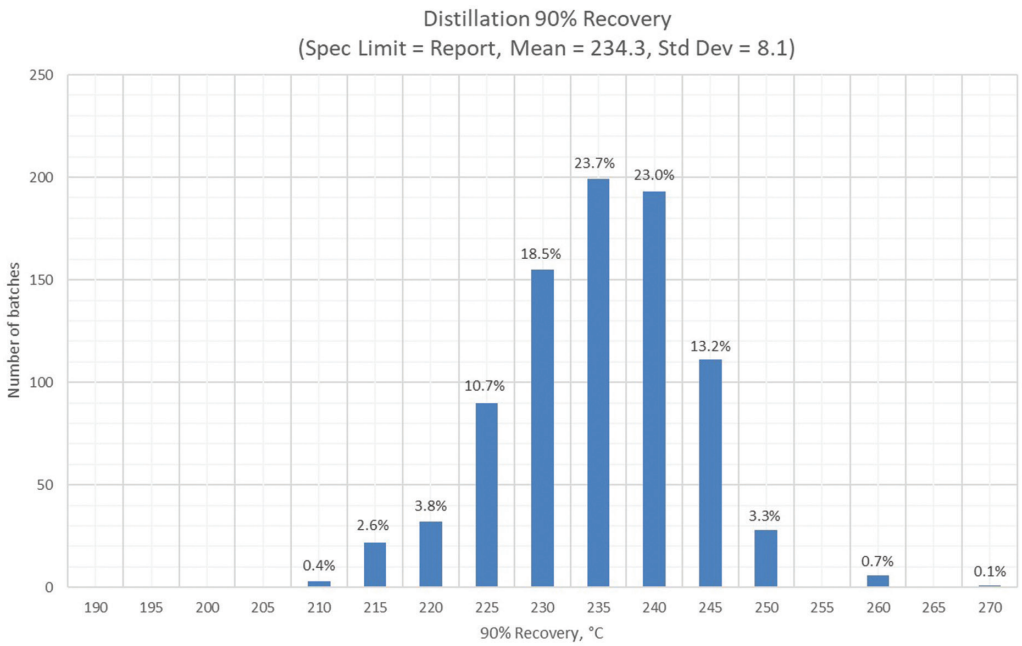


Figure B.23: Distillation 90 % recovery histogram (2022)

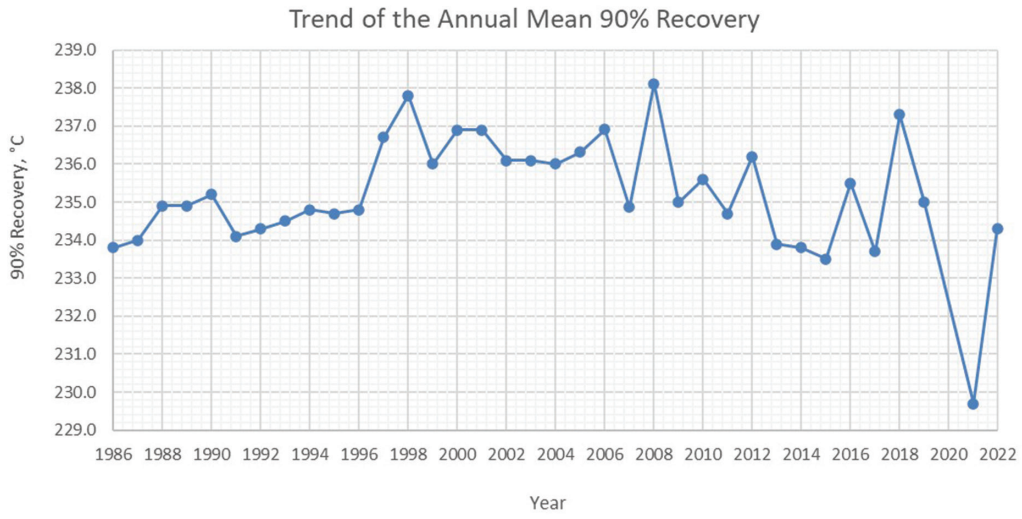


Figure B.24: Distillation 90 % recovery trend graph

B.9 DISTILLATION FBP

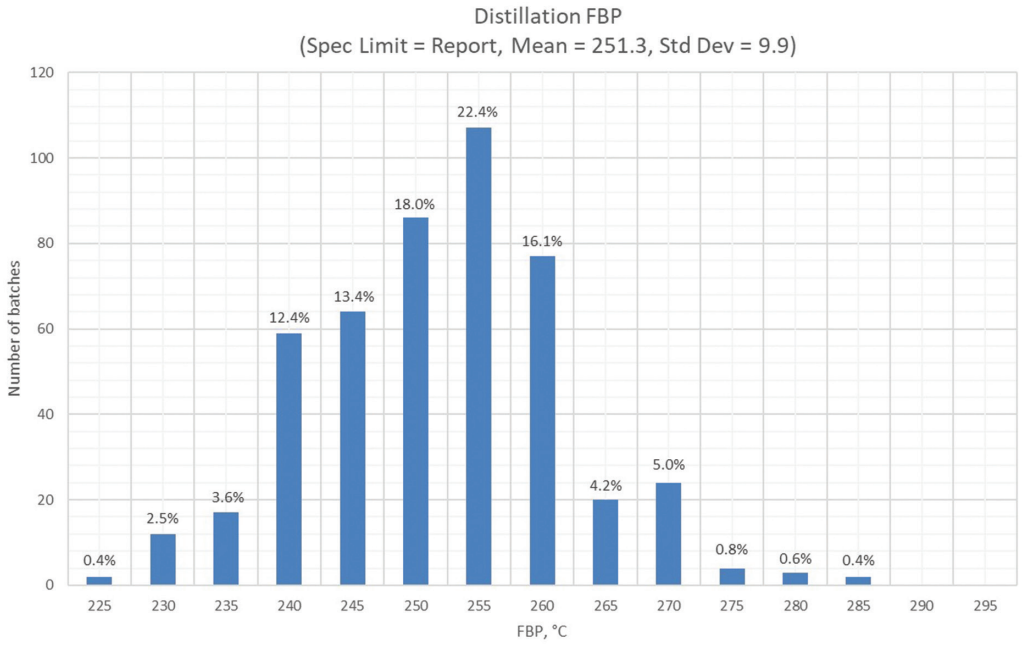


Figure B.25: Distillation FBP histogram (2021)

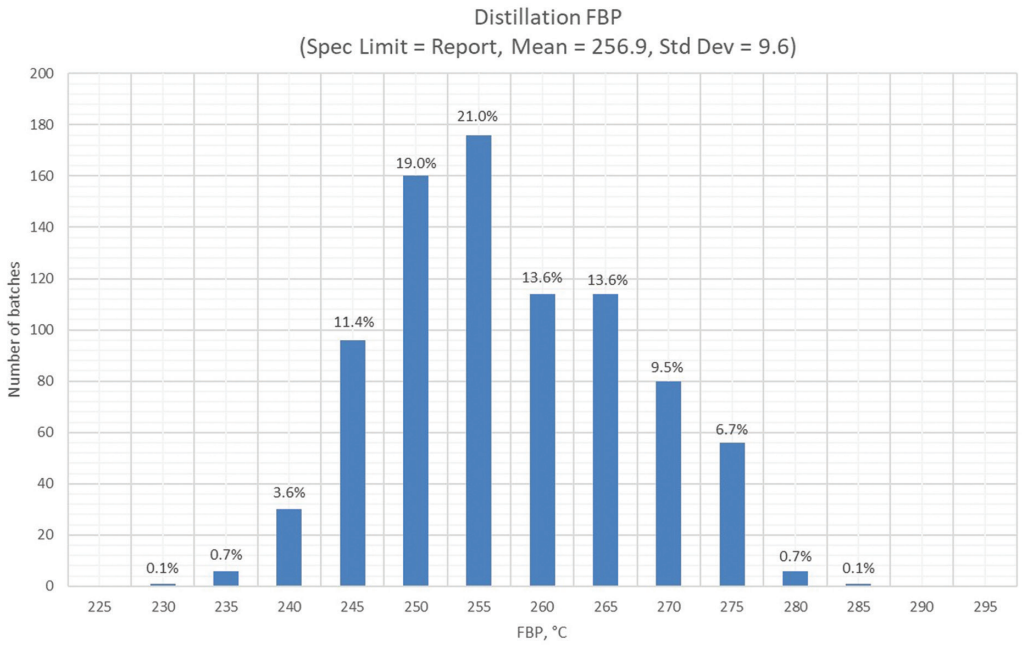


Figure B.26: Distillation FBP histogram (2022)

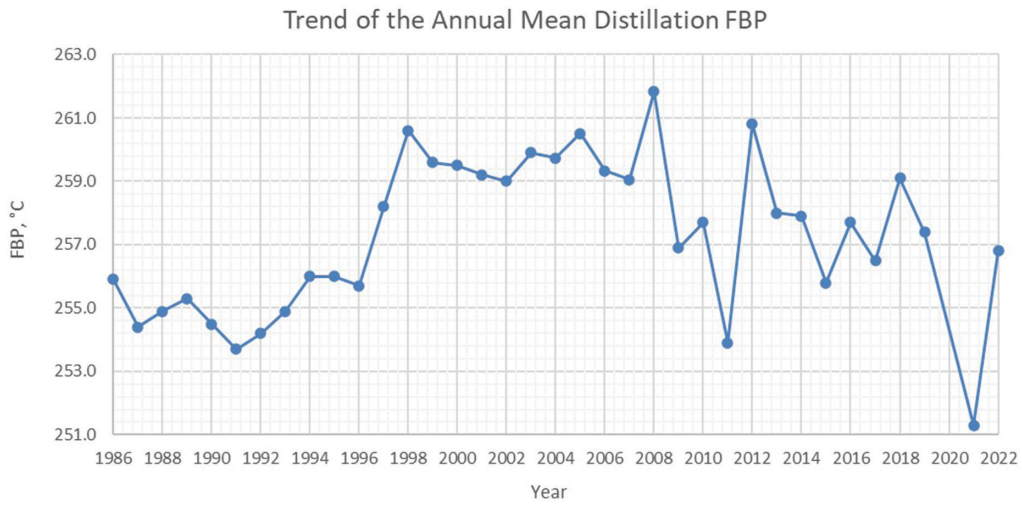


Figure B.27: Distillation FBP trend graph

B.10 DISTILLATION RANGE

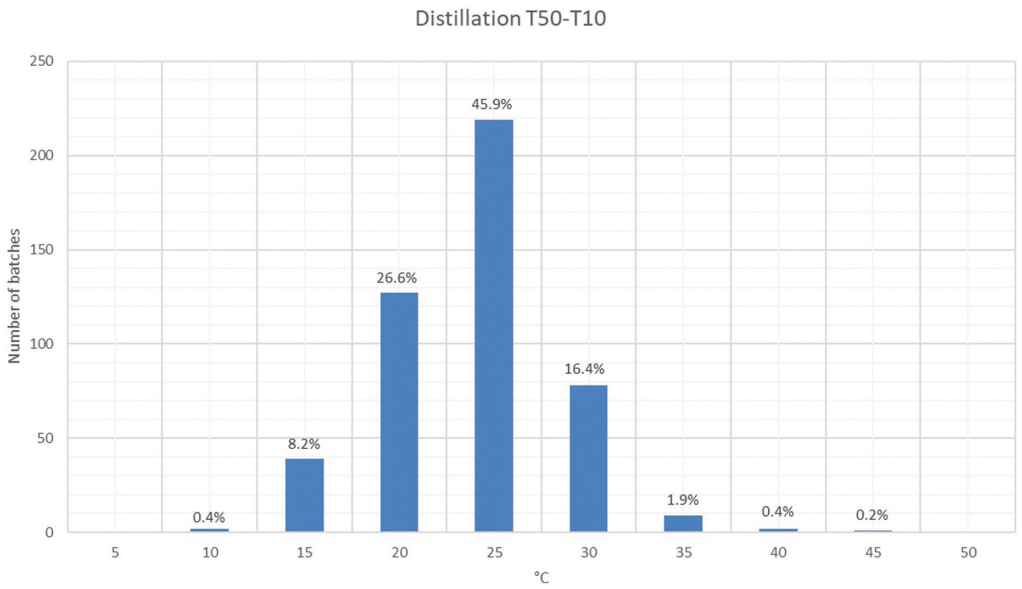


Figure B.28: Distillation T50-T10 (2021)

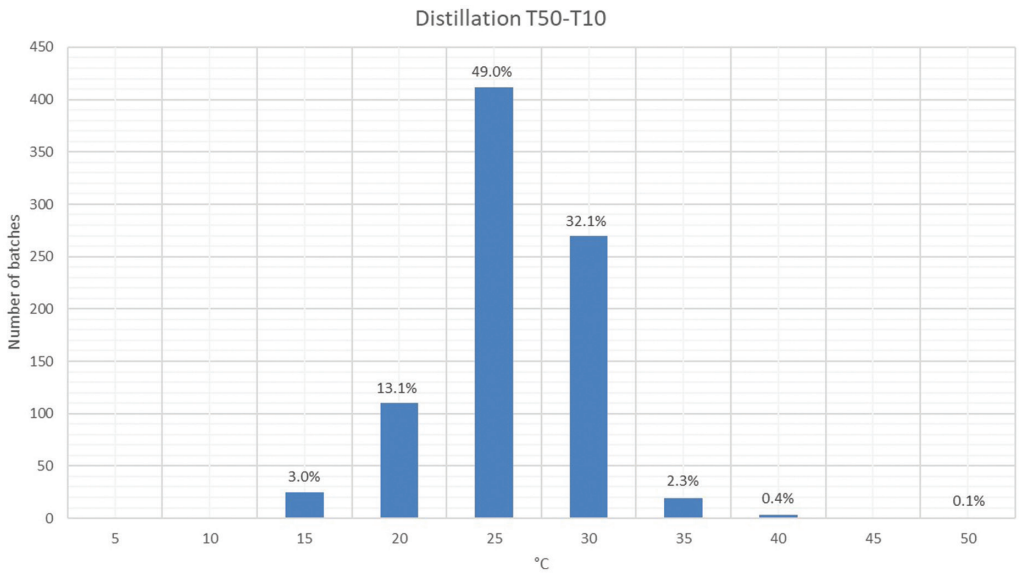


Figure B.29: Distillation T50-T10 (2022)

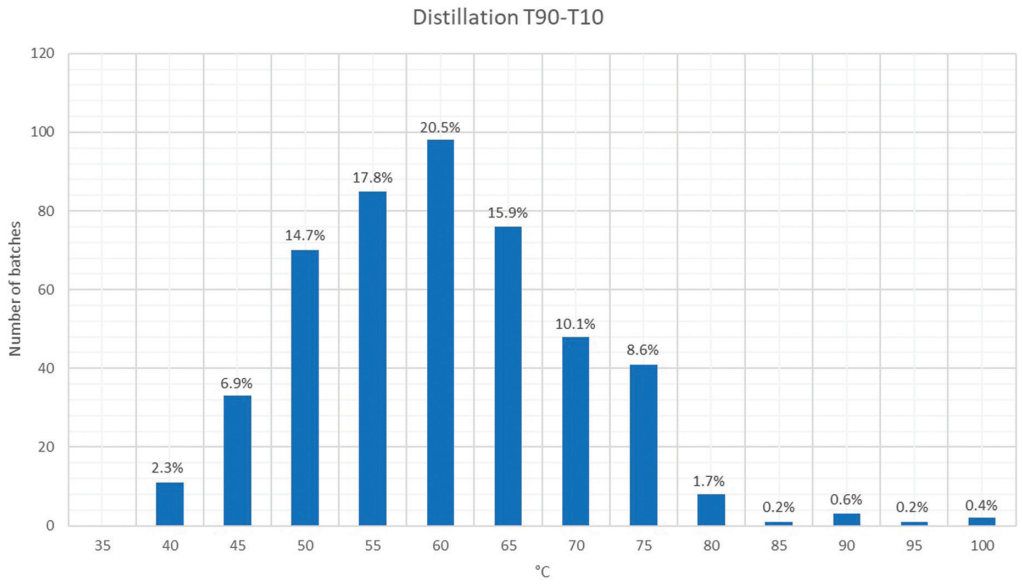


Figure B.30: Distillation T90-T10 (2021)

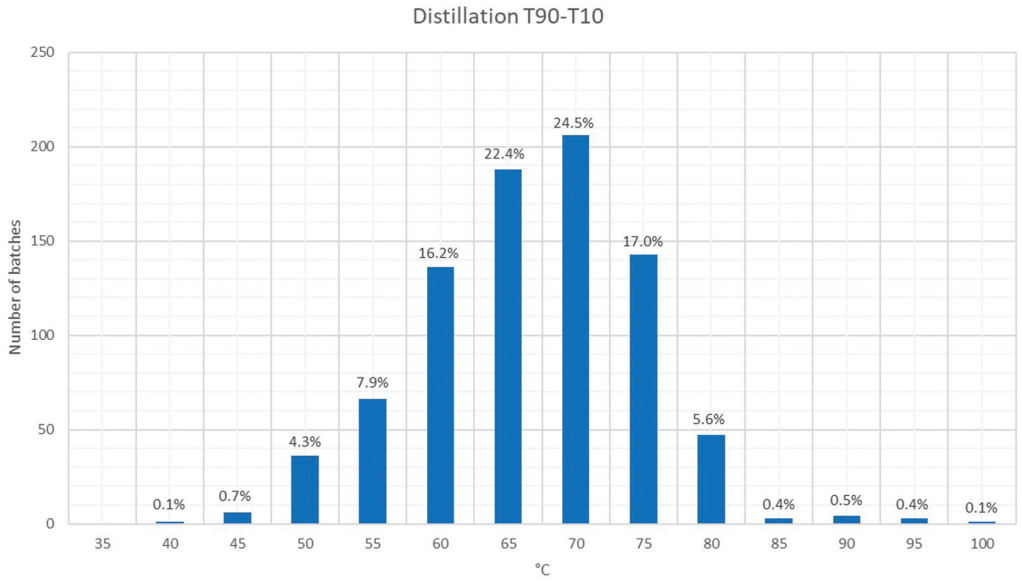


Figure B.31: Distillation T90-T10 (2022)

B.11 FLASH POINT

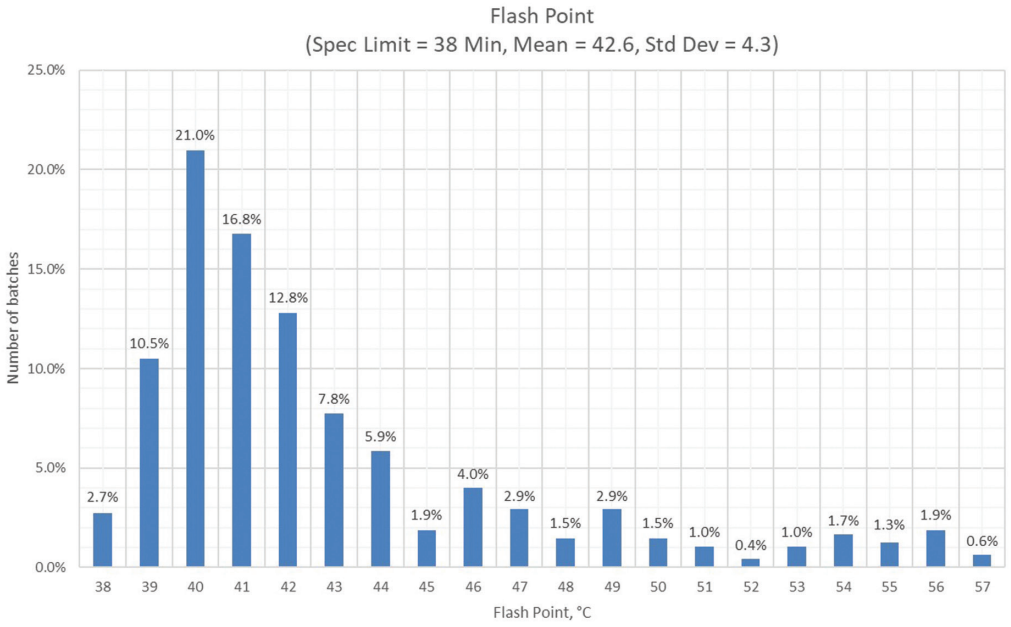


Figure B.32: Flash point histogram (2021)

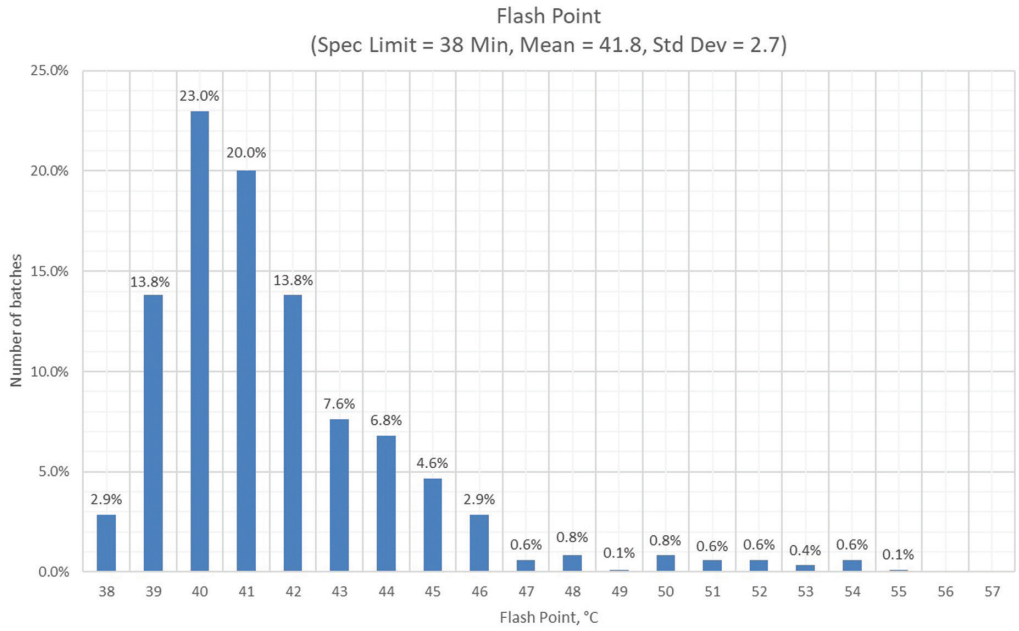


Figure B.33: Flash point histogram (2022)

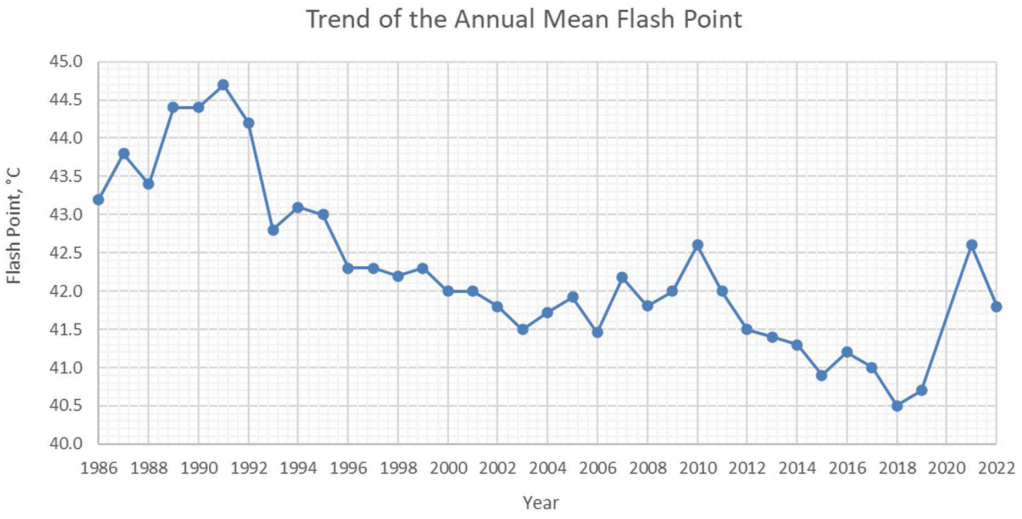


Figure B.34: Flash point trend graph

B.12 DENSITY AT 15 °C

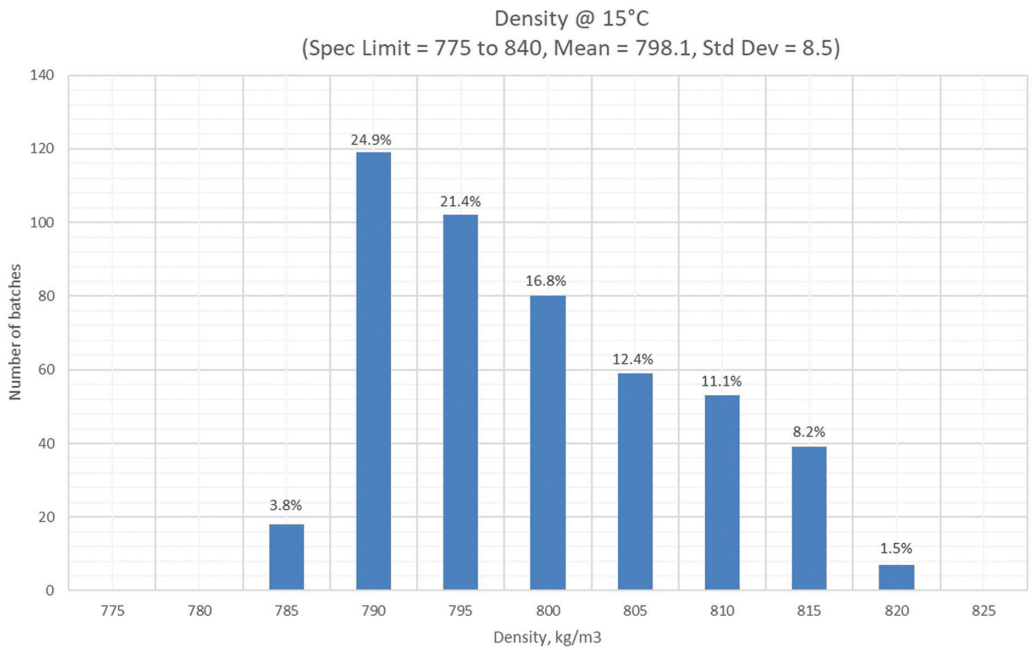


Figure B.35: Density histogram (2021)

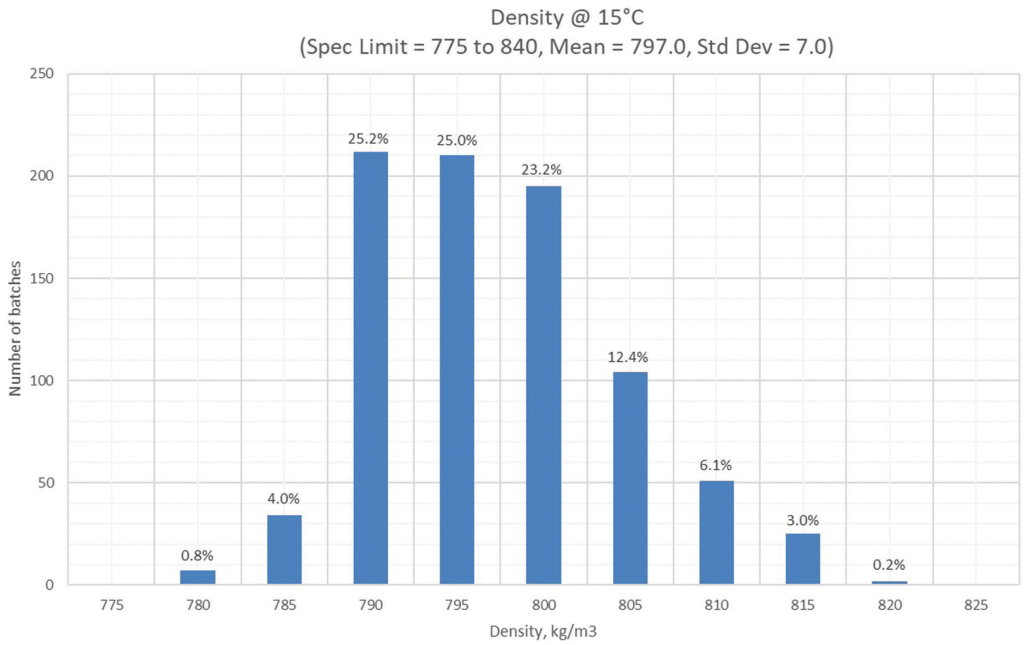


Figure B.36: Density histogram (2022)

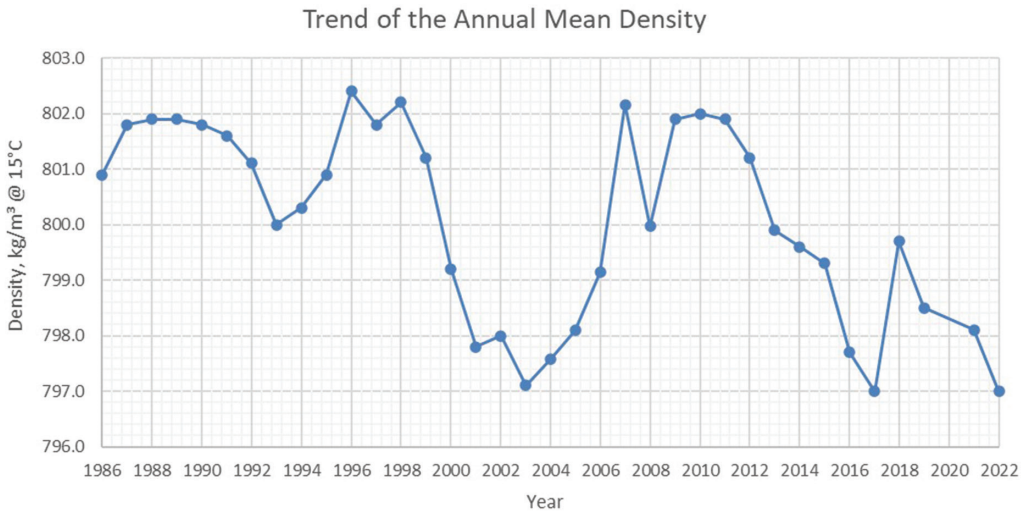


Figure B.37: Density trend graph

B.13 FREEZING POINT

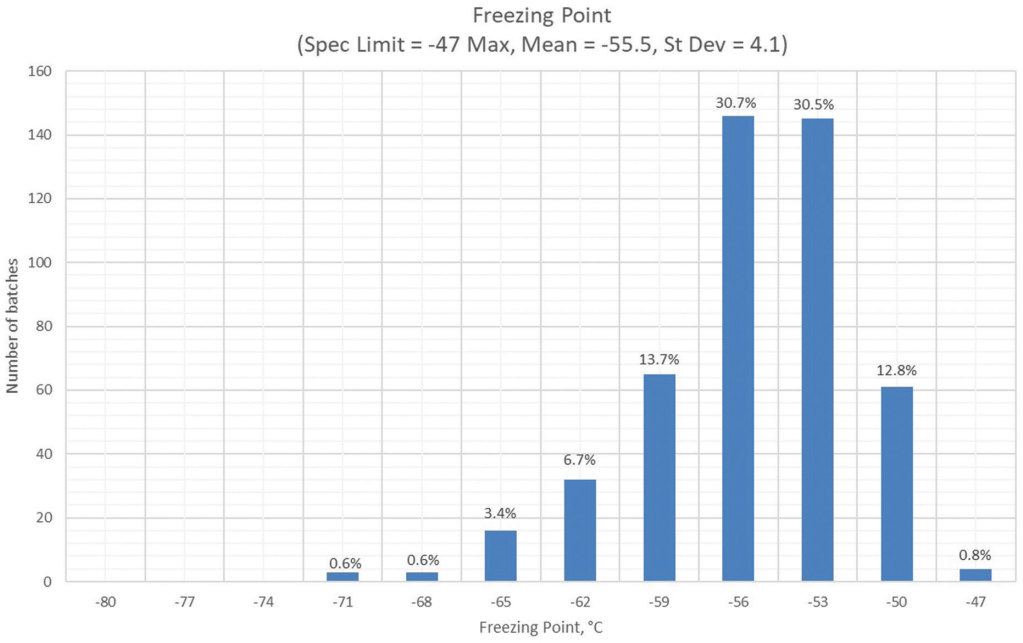


Figure B.38: Freezing point histogram (2021)

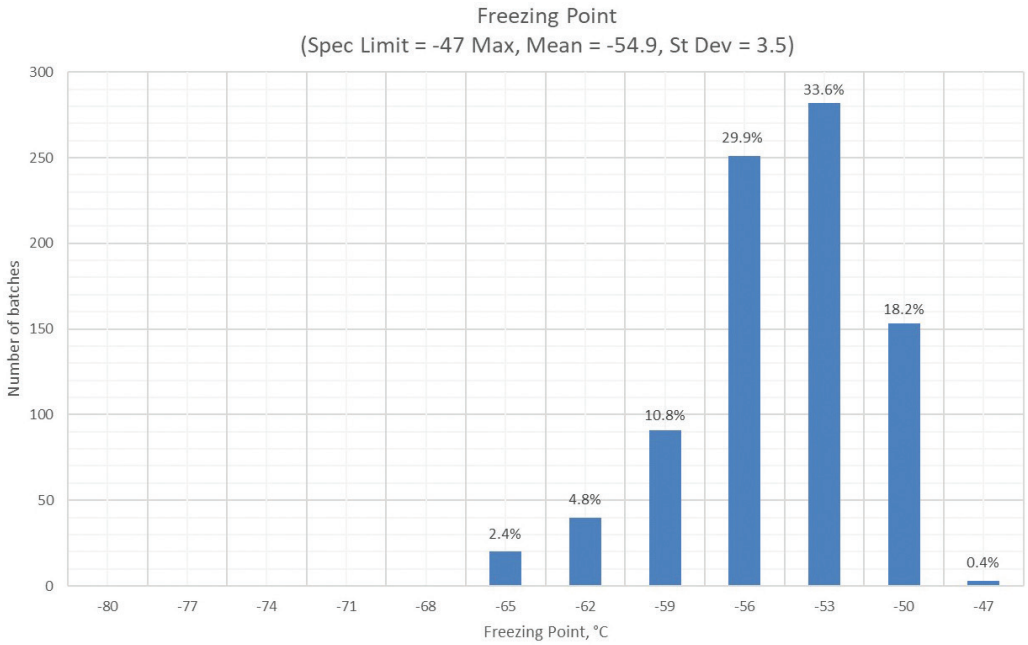


Figure B.39: Freezing point histogram (2022)

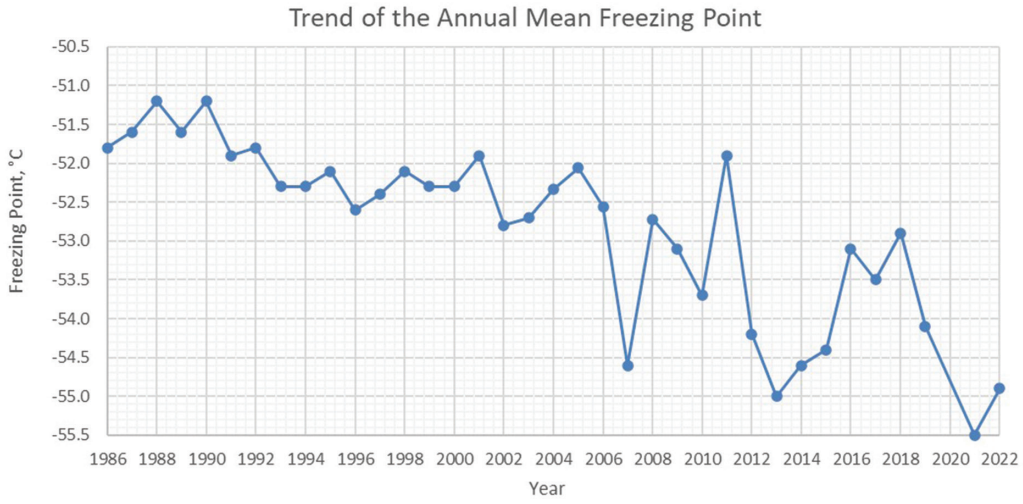


Figure B.40: Freezing point trend graph

B.14 KINEMATIC VISCOSITY AT –20 °C

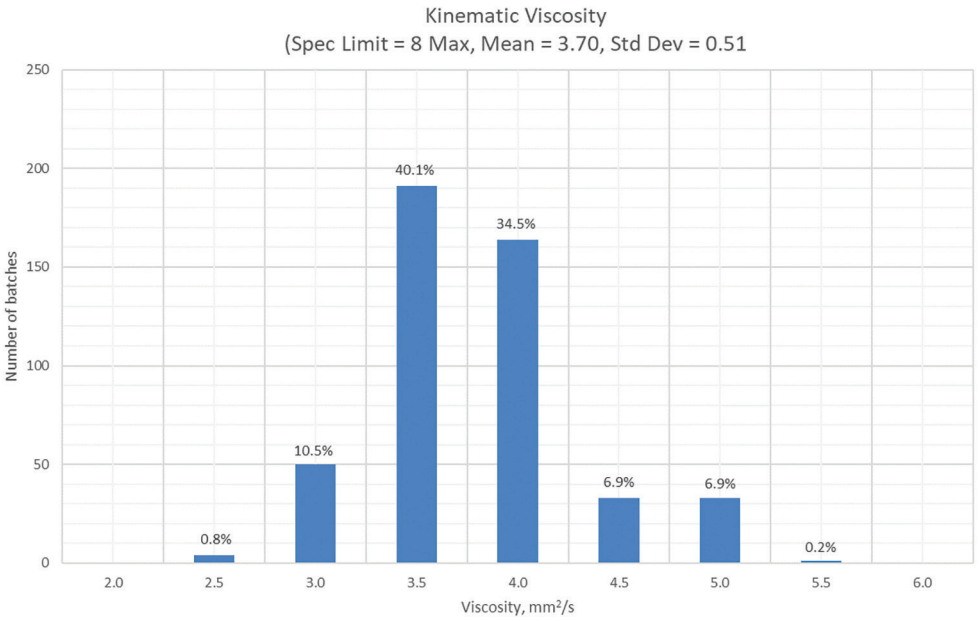


Figure B.41: Kinematic viscosity histogram (2021)

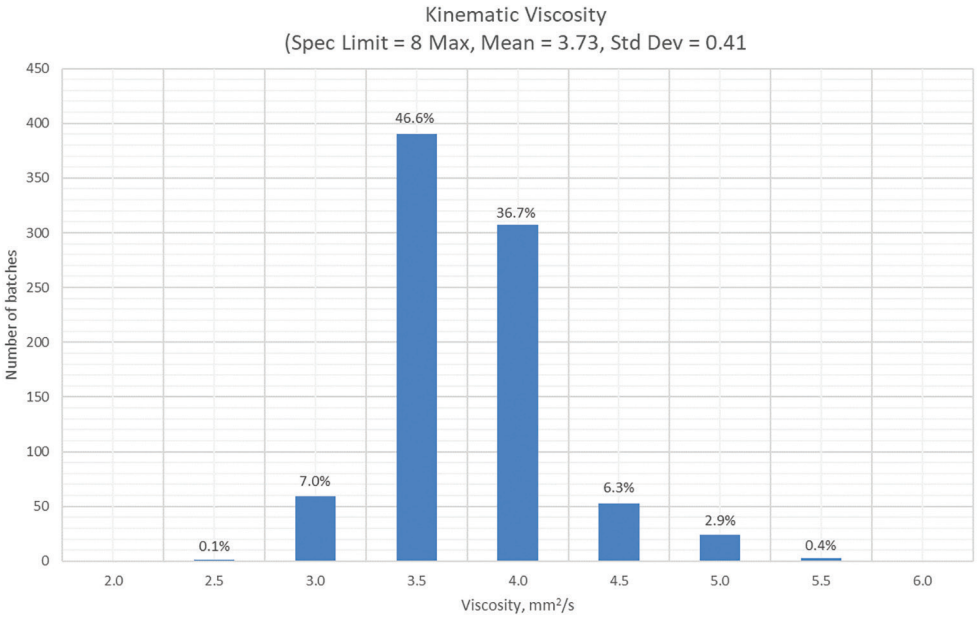


Figure B.42: Kinematic viscosity histogram (2022)

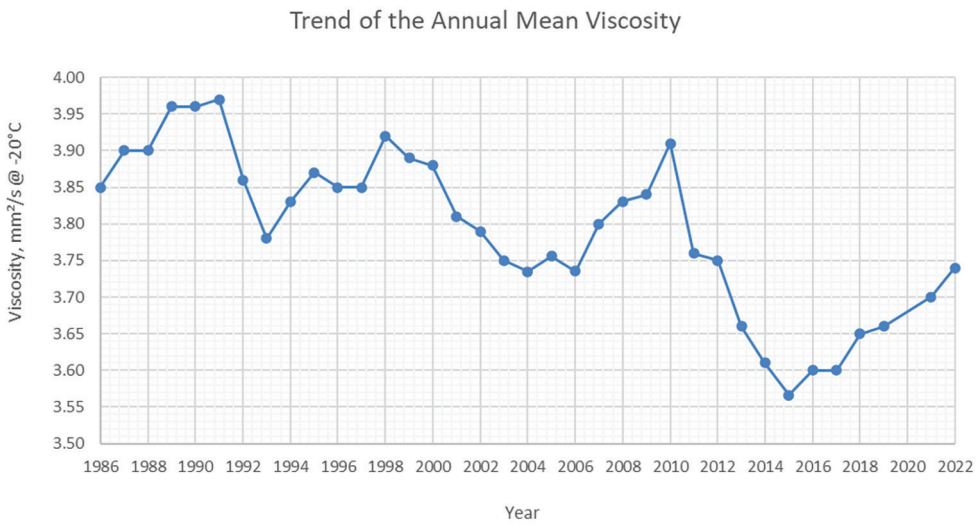


Figure B.43: Kinematic viscosity trend graph

B.15 SPECIFIC ENERGY

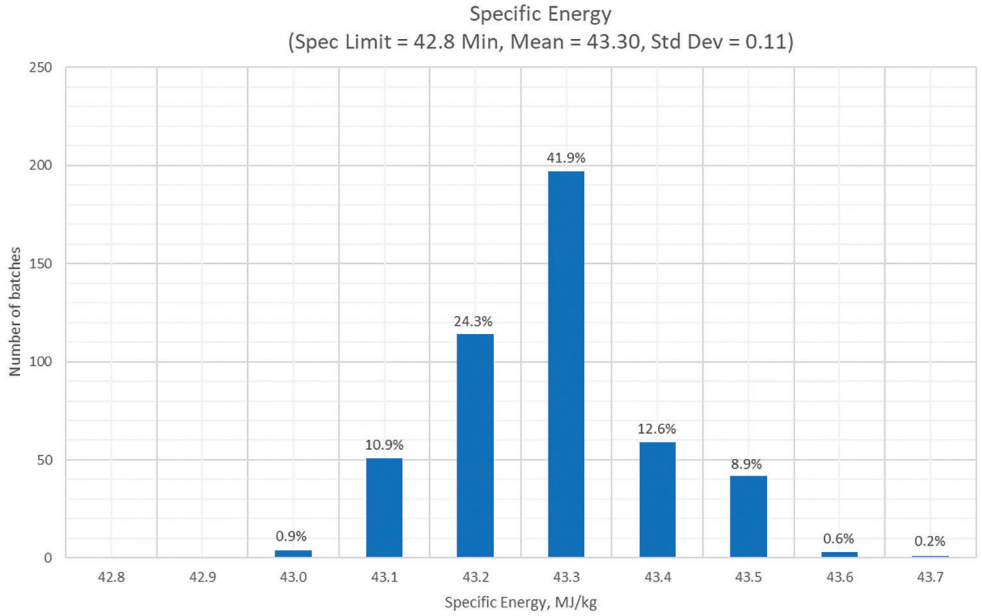


Figure B.44: Specific energy histogram (2021)

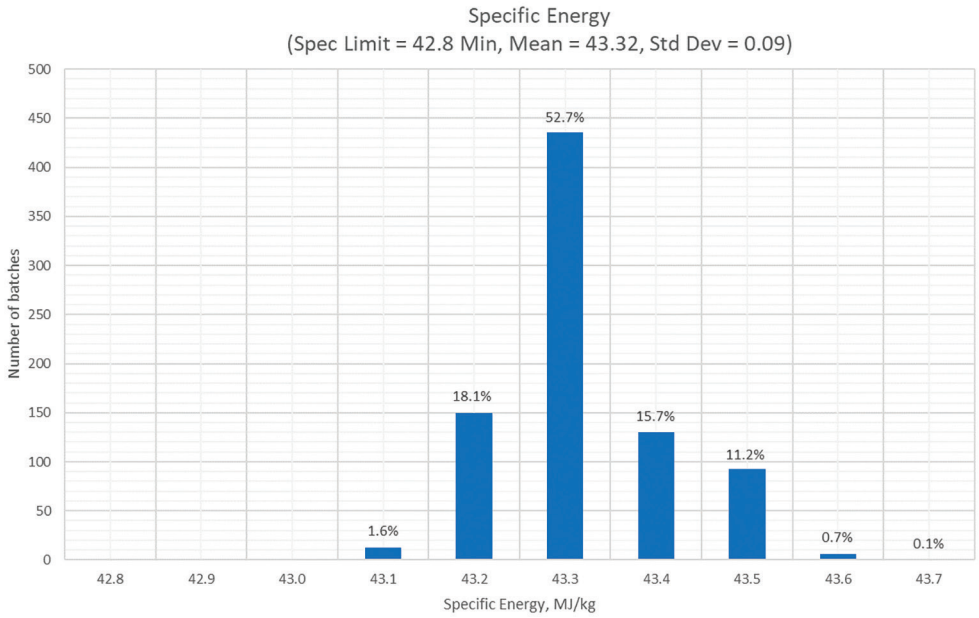


Figure B.45: Specific energy histogram (2022)

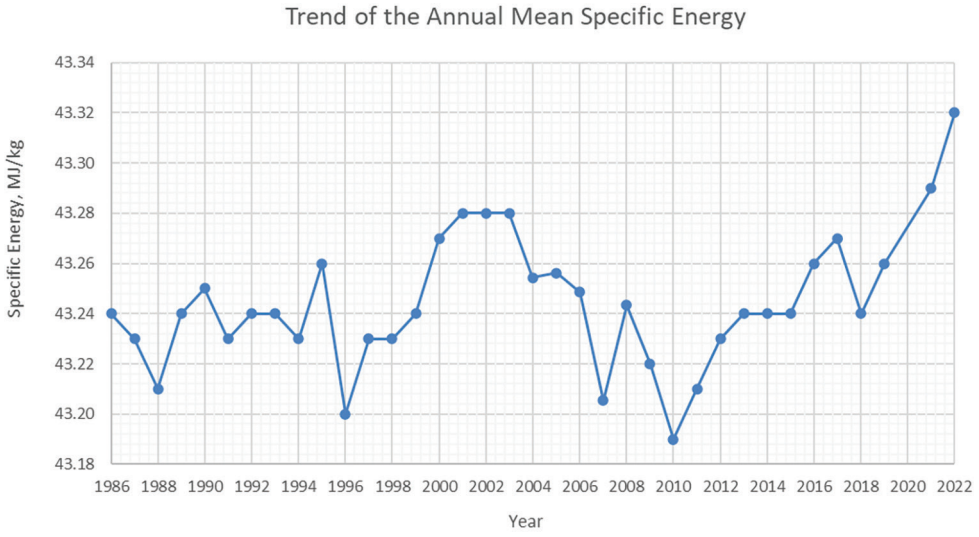


Figure B.46: Specific energy trend graph

B.16 SMOKE POINT

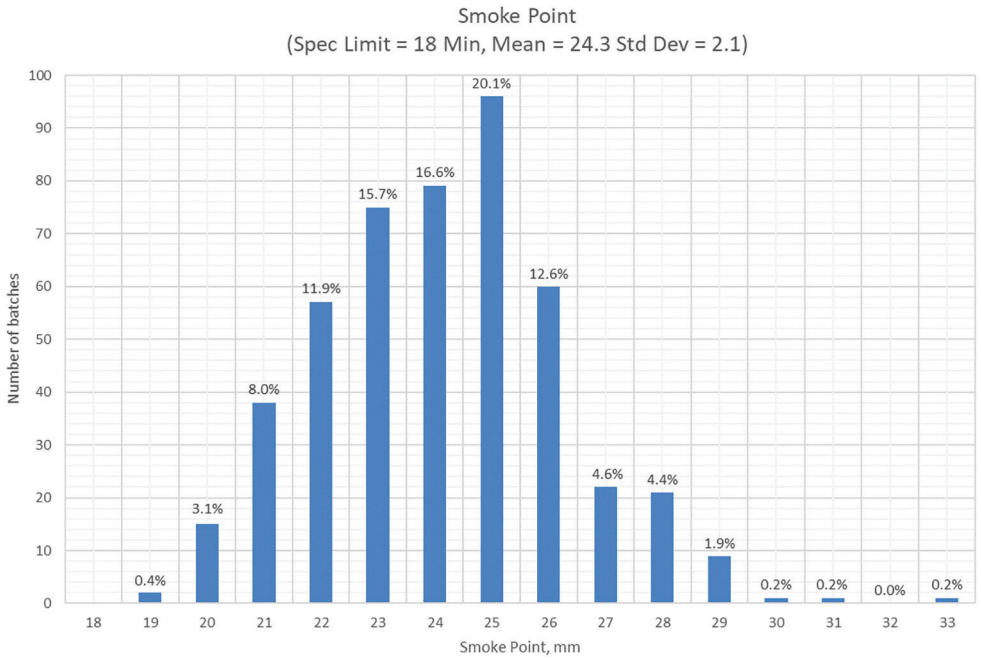


Figure B.47: Smoke point histogram (2021)

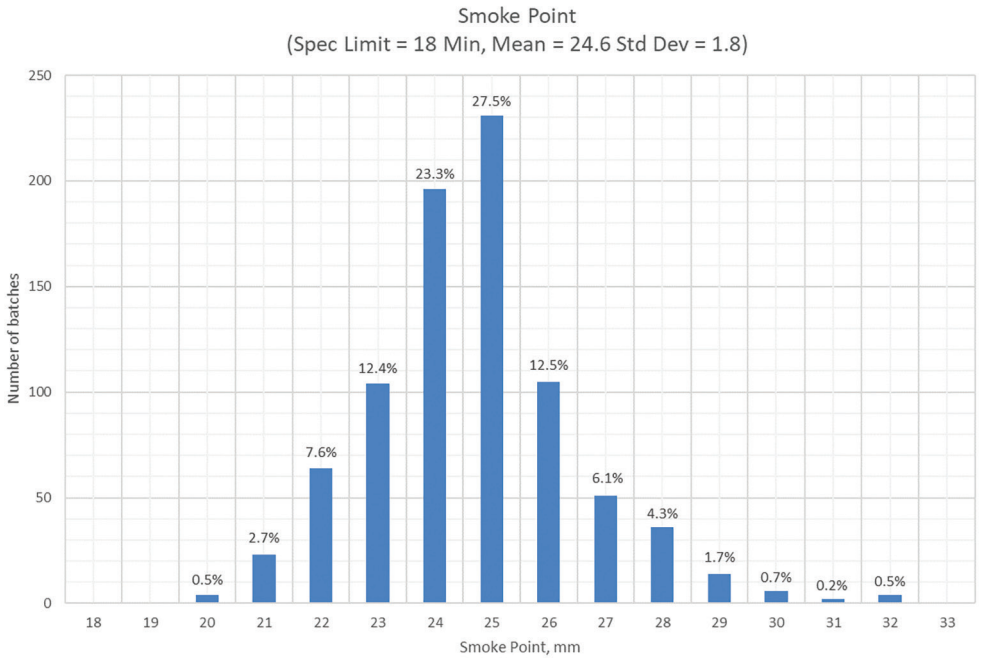


Figure B.48: Smoke point histogram (2022)

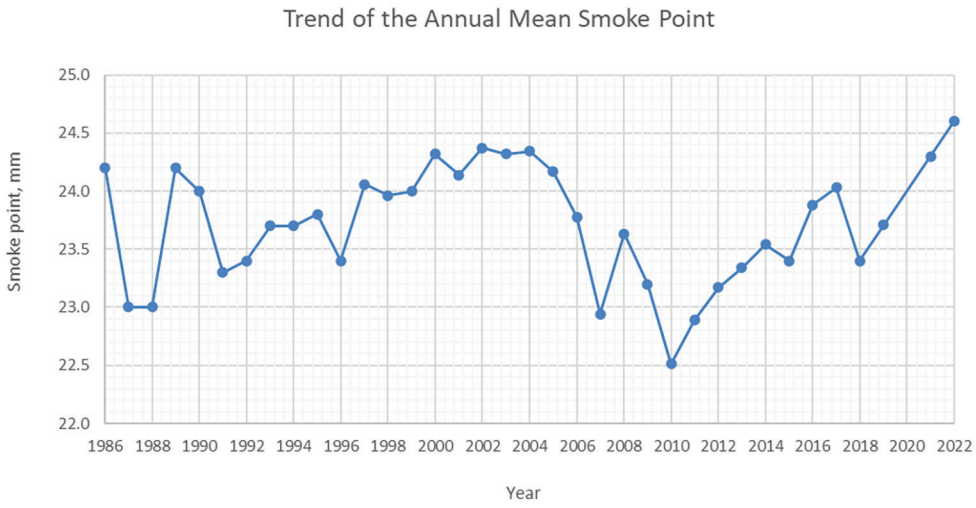


Figure B.49: Smoke point trend graph

B.17 NAPHTHALENES

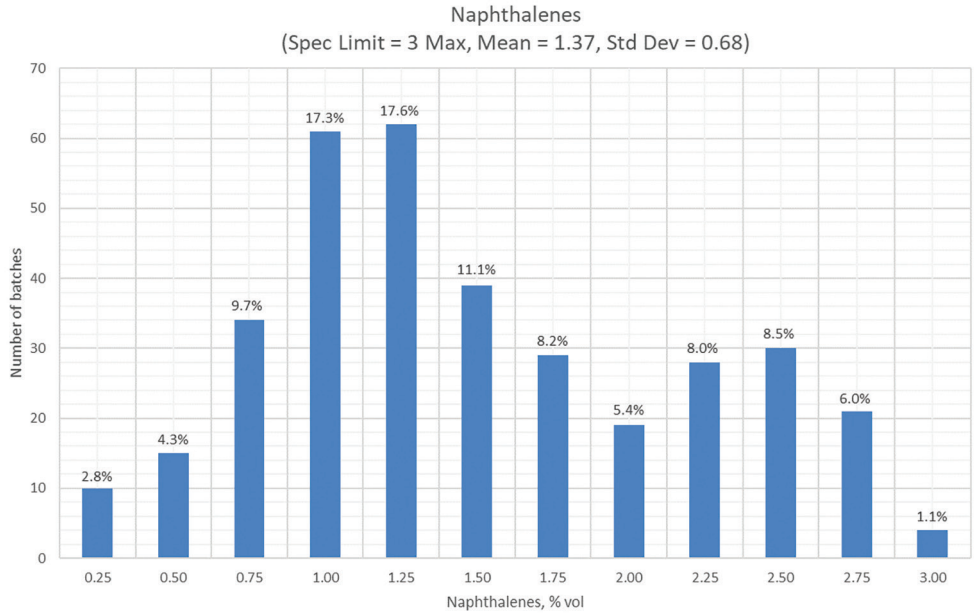


Figure B.50: Naphthalenes histogram (2021)

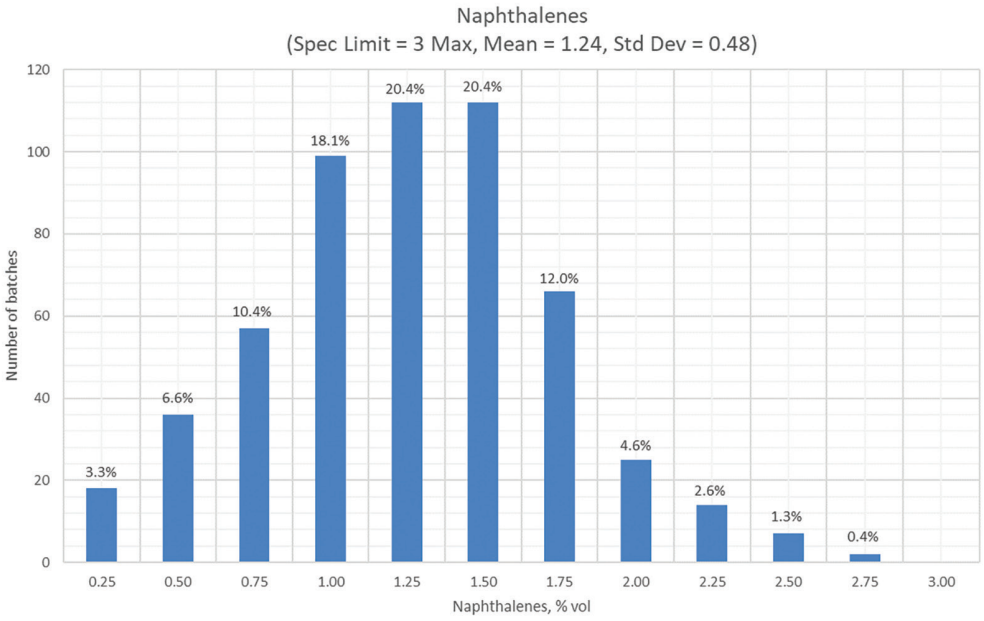


Figure B.51: Naphthalenes histogram (2022)

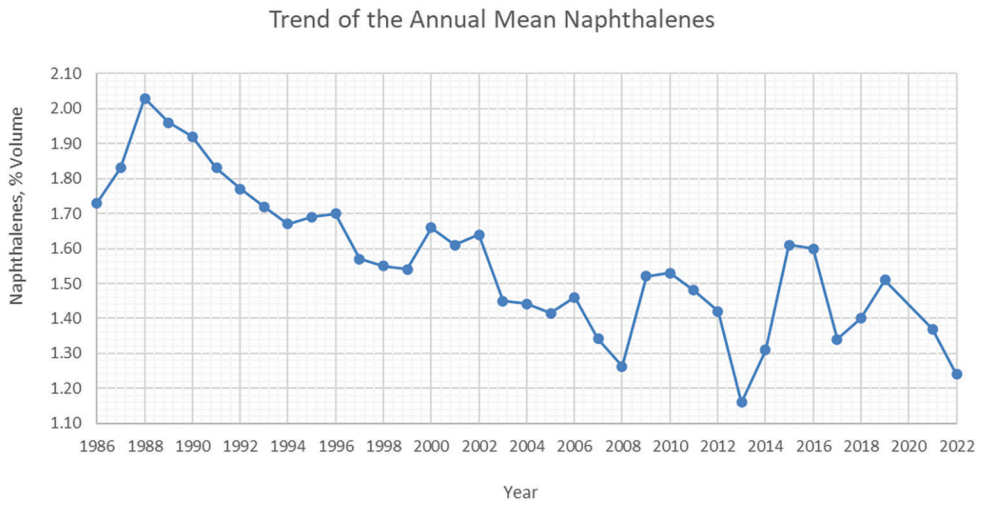


Figure B.52: Naphthalenes trend graph

B.18 EXISTENT GUM

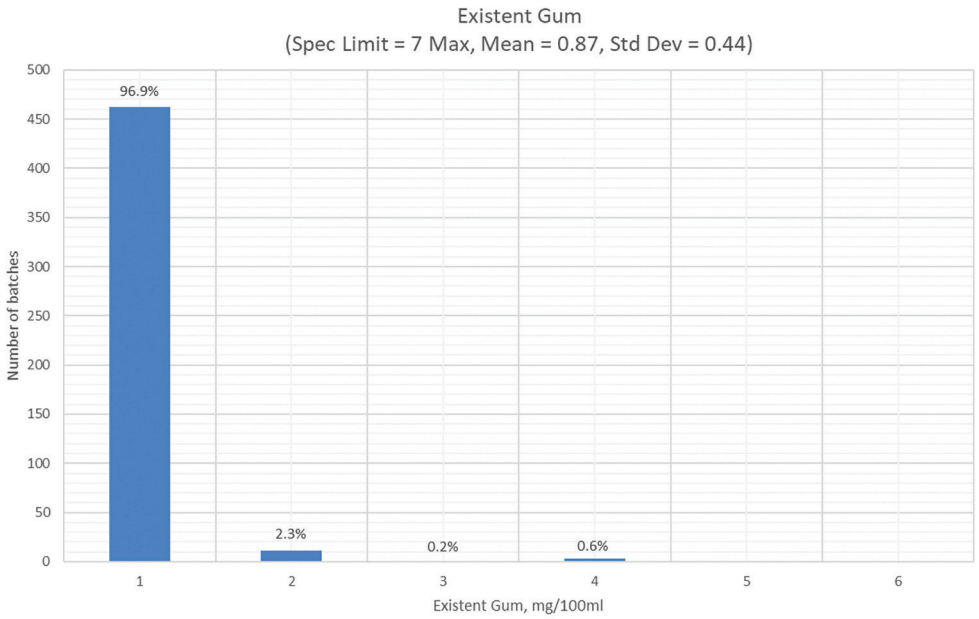


Figure B.53: Existent gum histogram (2021)

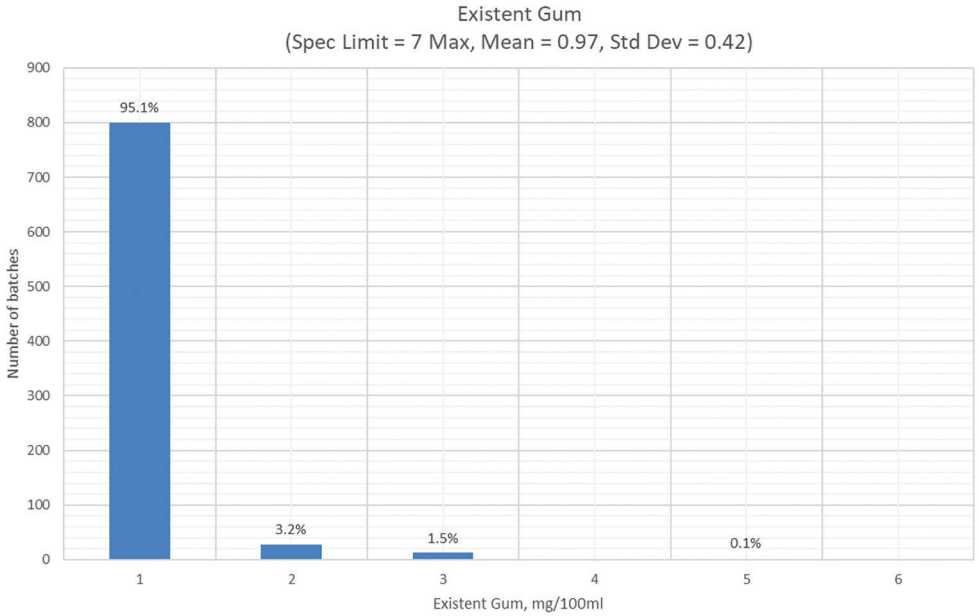


Figure B.54: Existent gum histogram (2022)

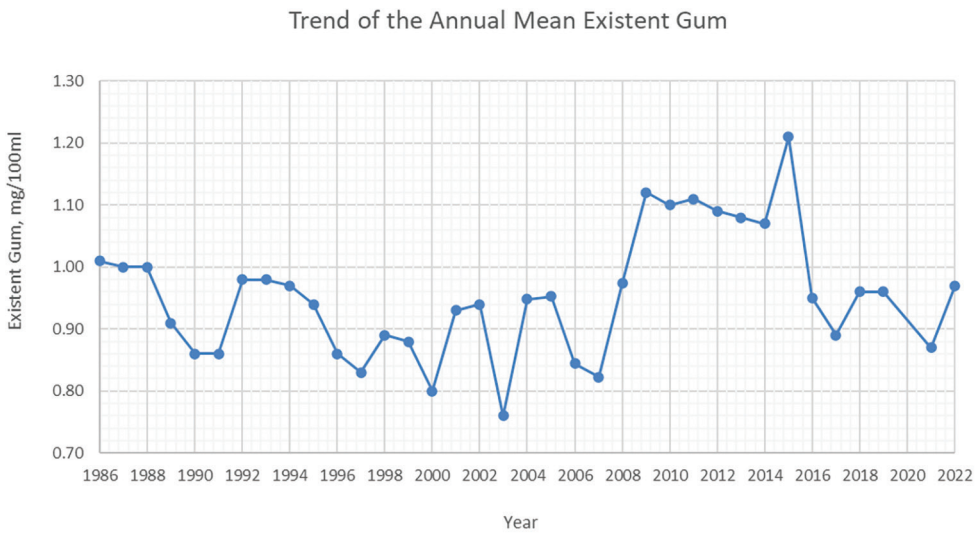


Figure B.55: Existent gum trend graph

B.19 MSEP®

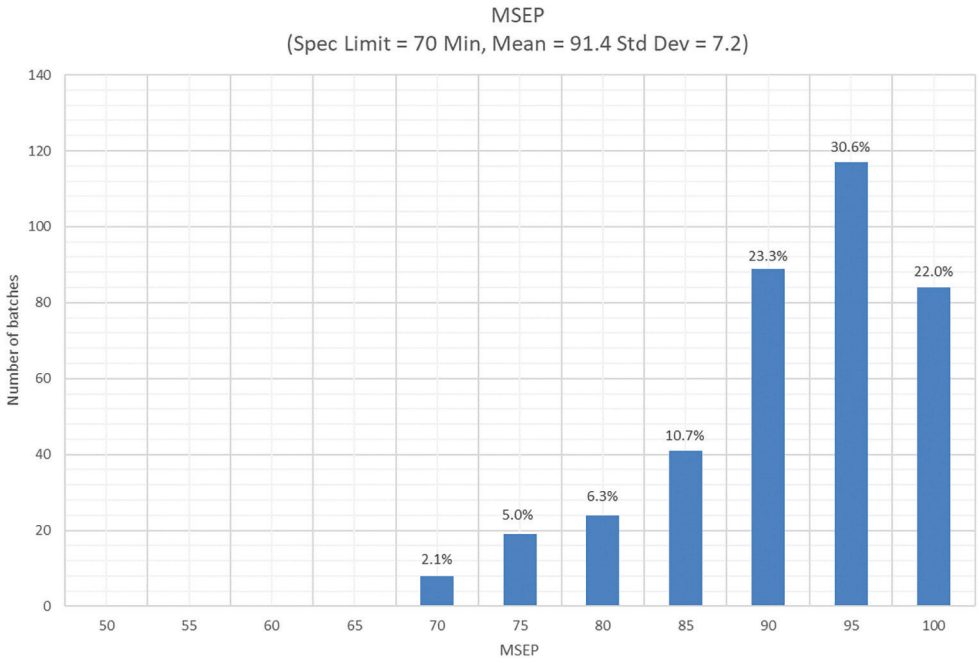


Figure B.56: MSEP® histogram (2021)

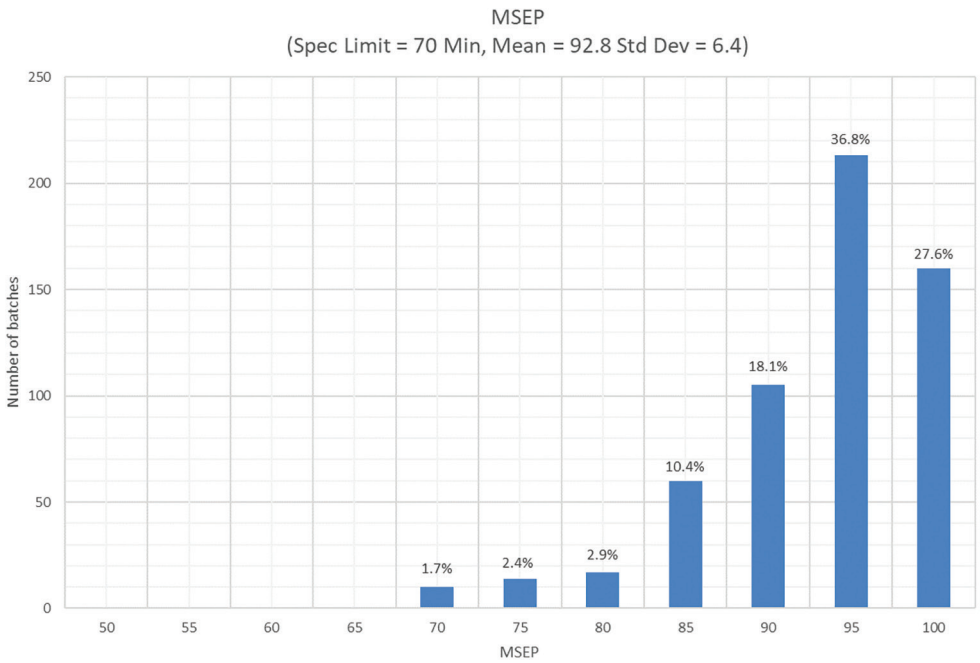


Figure B.57: MSEP® histogram (2022)

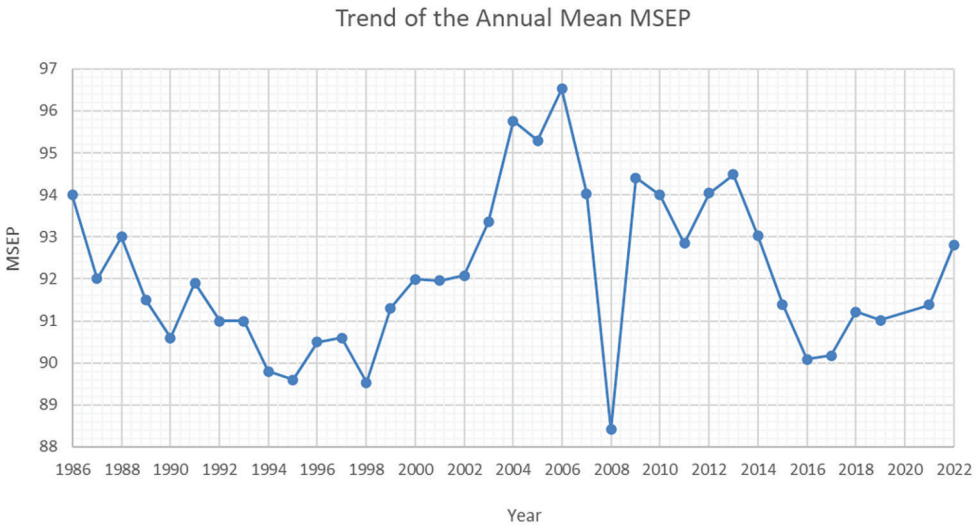


Figure B.58: MSEP® trend graph

B.20 PARTICULATE (GRAVIMETRIC)

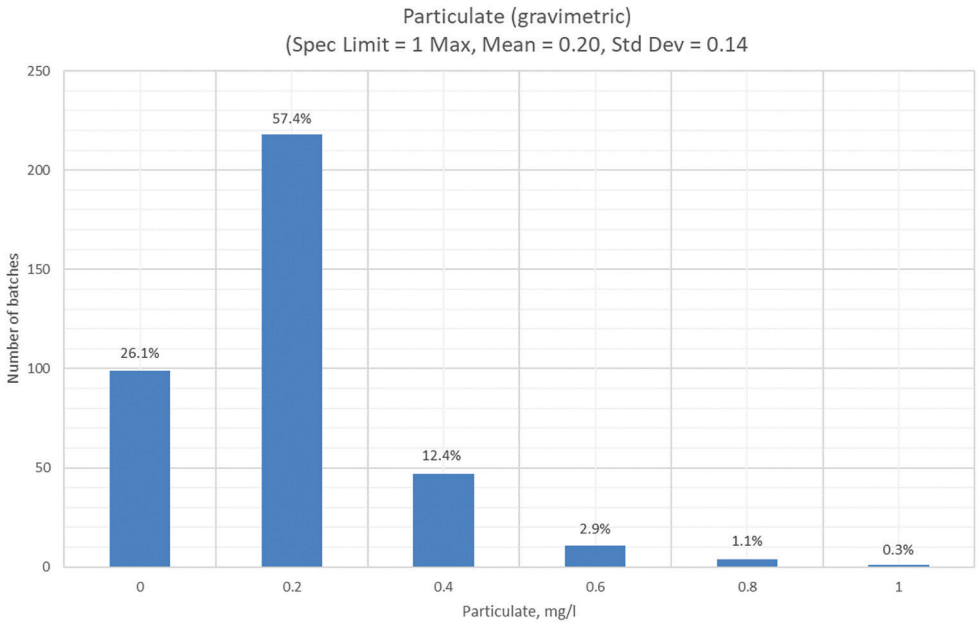


Figure B.59: Particulate histogram (2021)

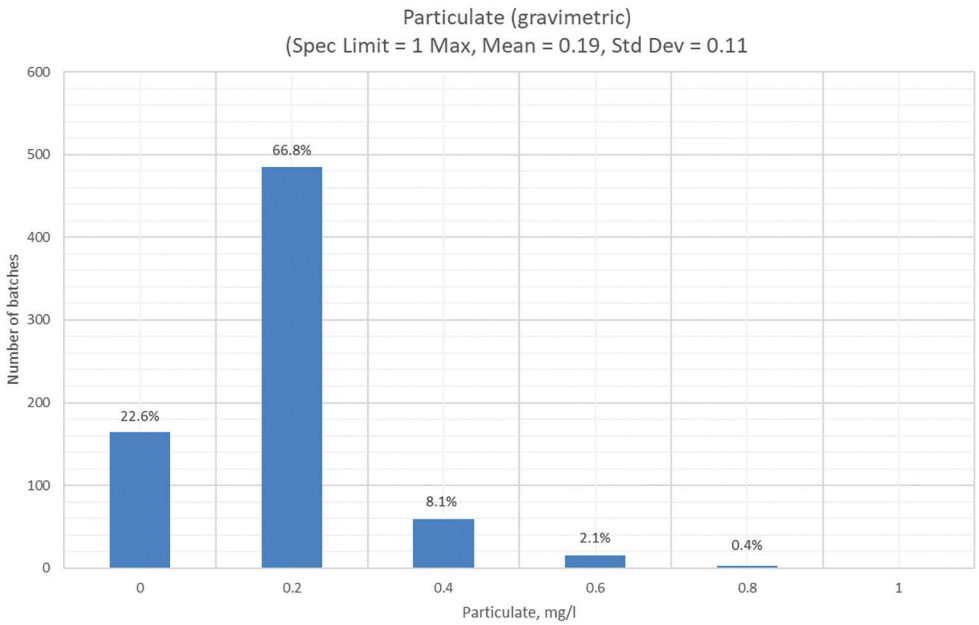


Figure B.60: Particulate histogram (2022)

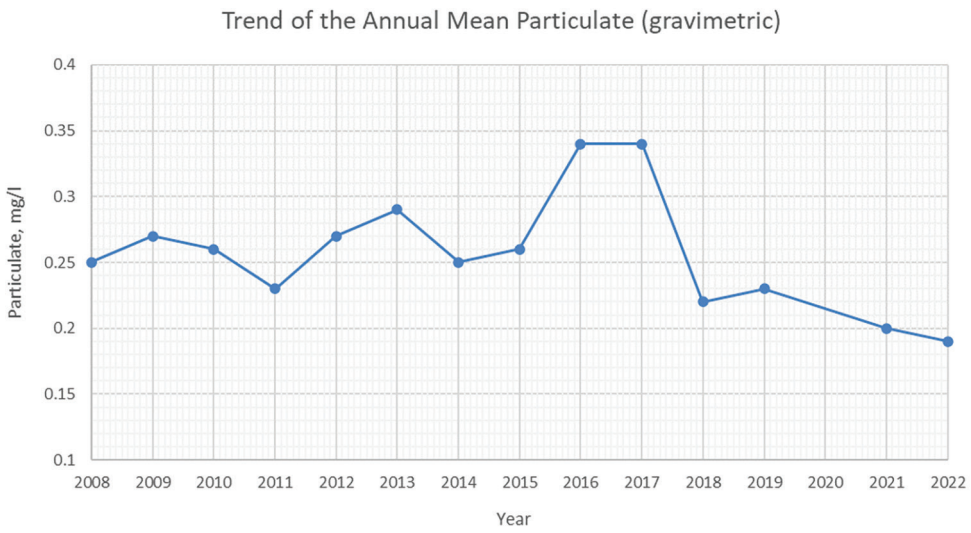


Figure B.61: Particulate trend graph

B.21 SAYBOLT COLOUR

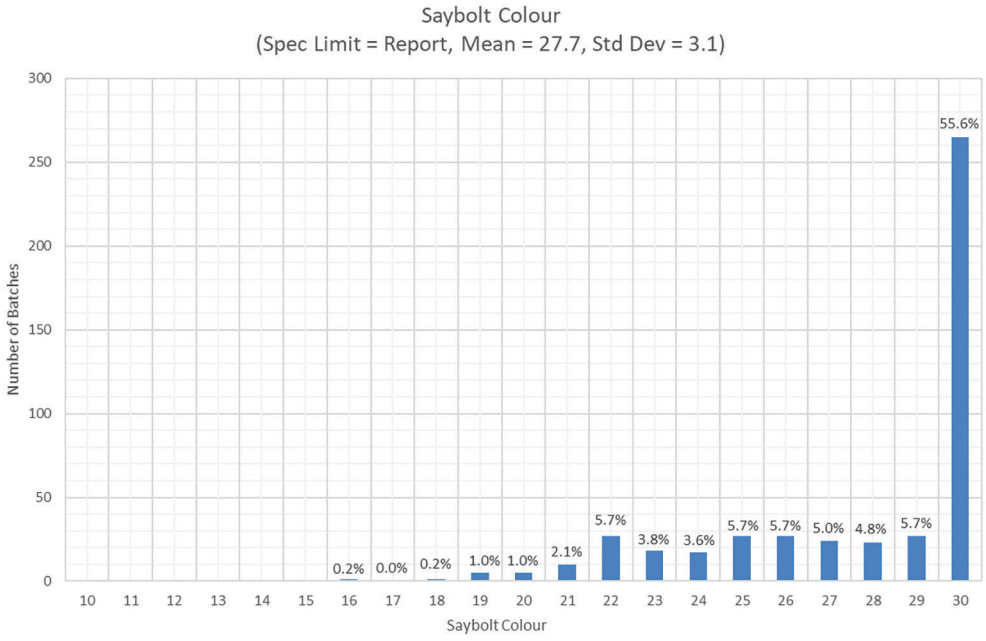


Figure B.62: Saybolt colour histogram (2021)

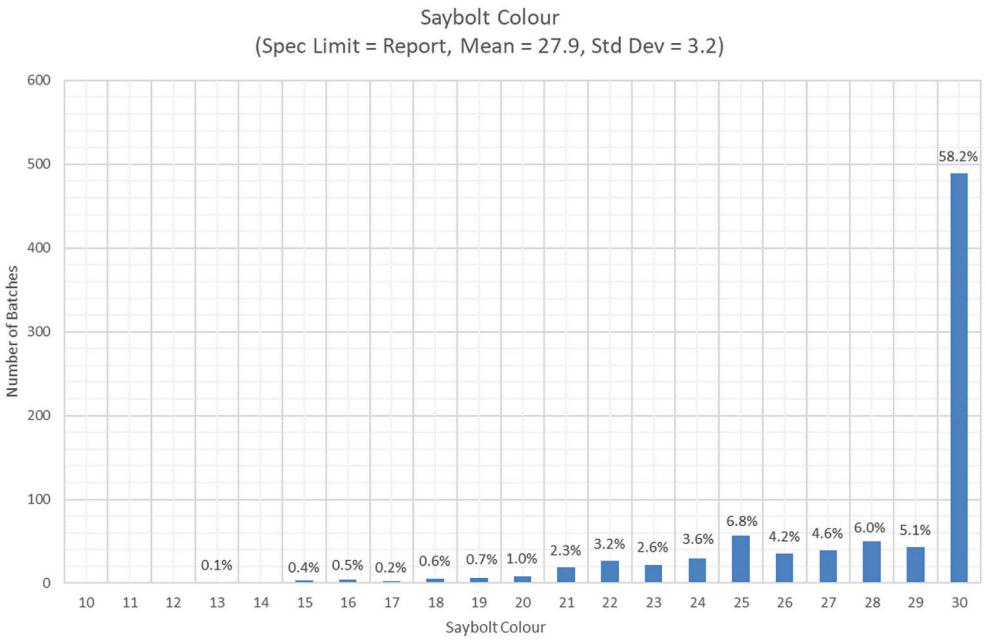


Figure B.63: Saybolt colour histogram (2022)

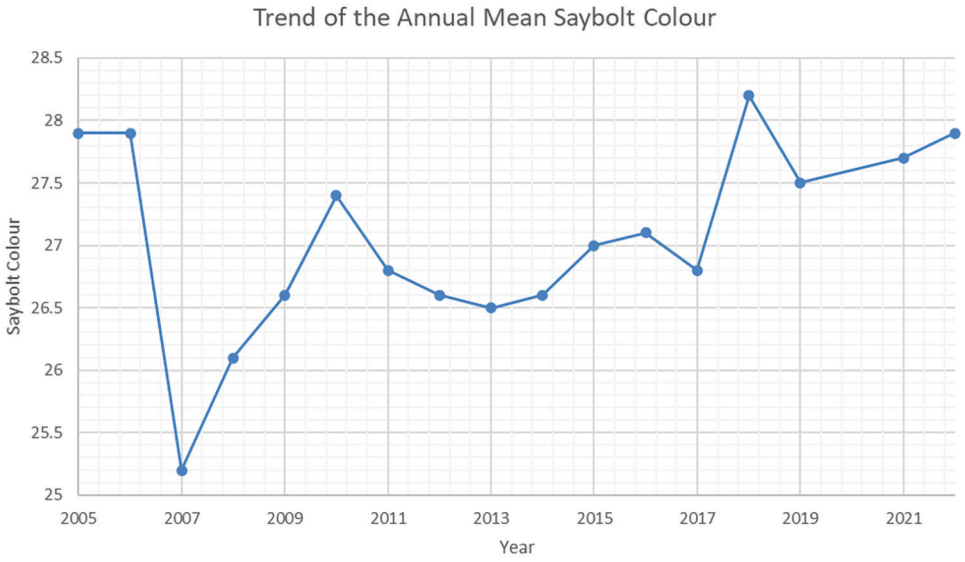


Figure B.64: Saybolt colour trend graph

B.22 PARTICLE COUNTS

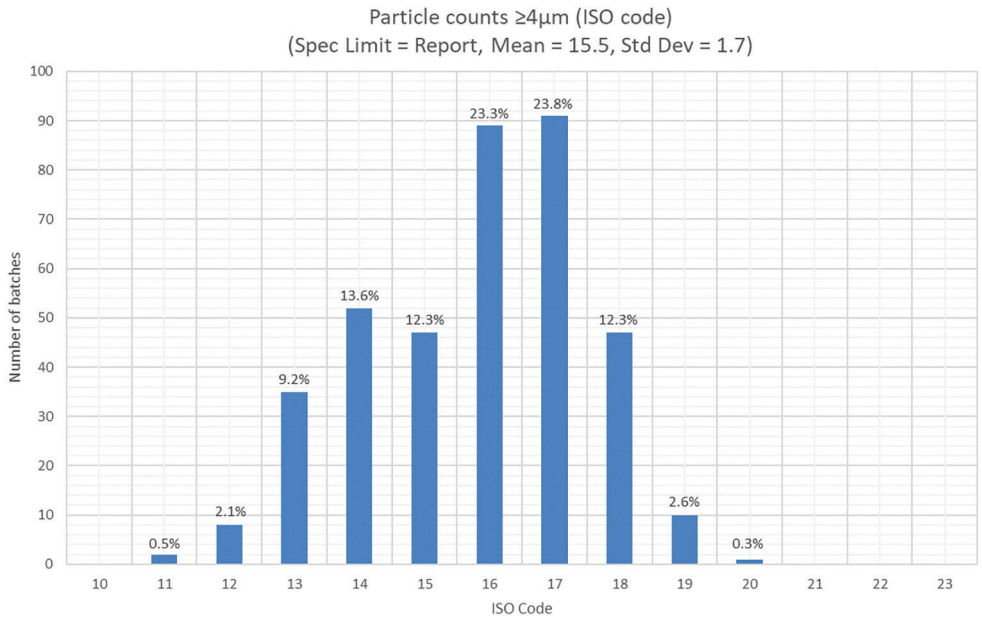


Figure B.65: Particle counts ≥4 µm ISO code (2021)

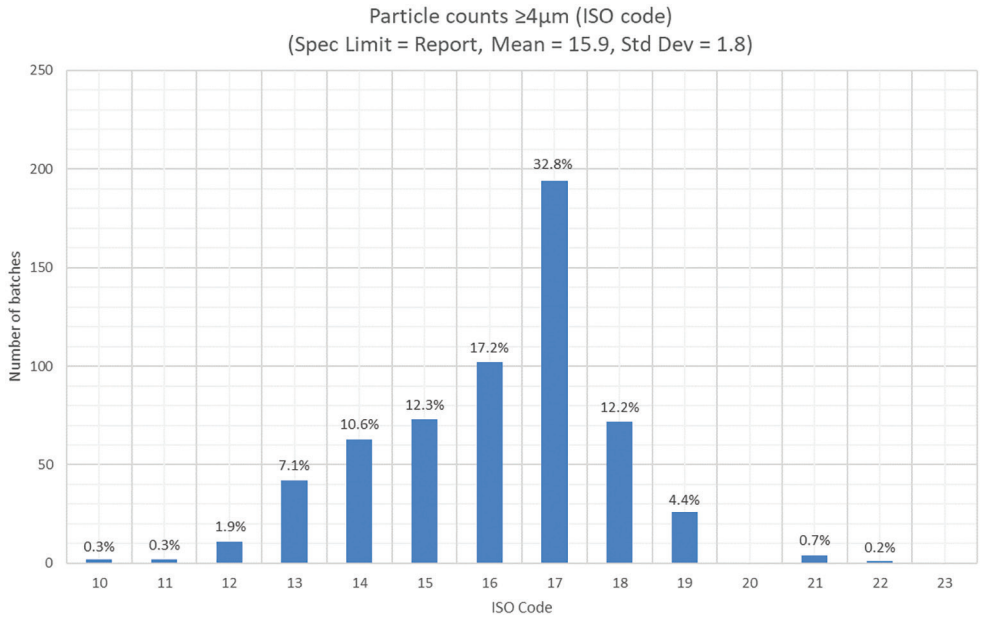


Figure B.66: Particle counts ≥4 µm ISO code (2022)

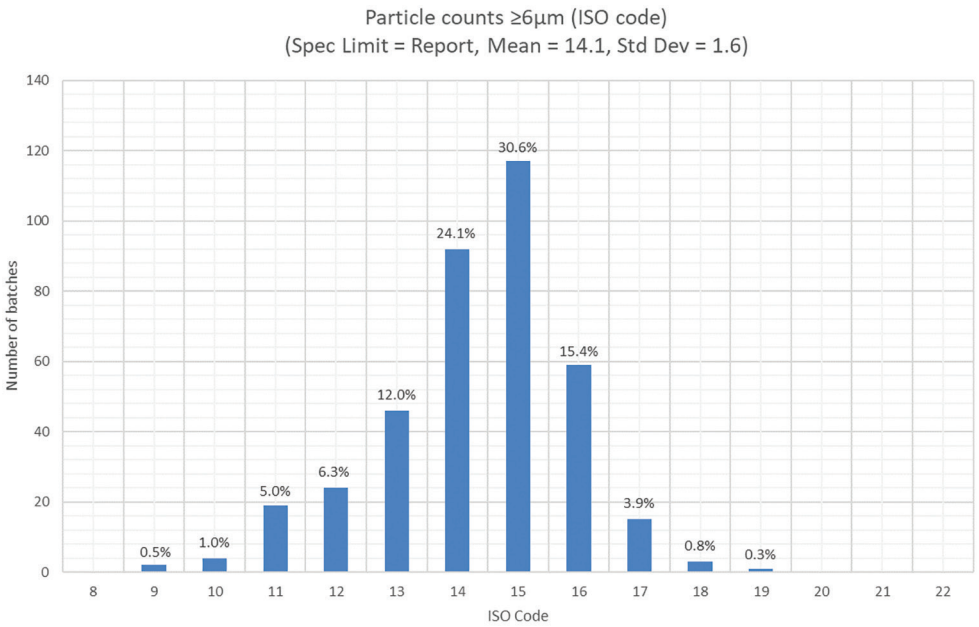


Figure B.67: Particle counts ≥6 µm ISO code (2021)

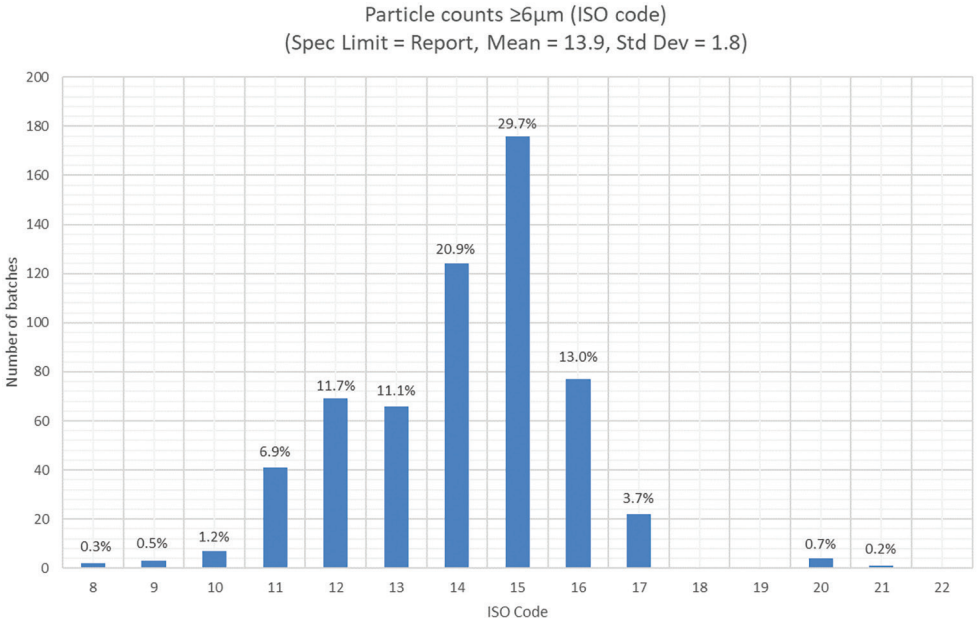


Figure B.68: Particle counts ≥6 µm ISO code (2022)

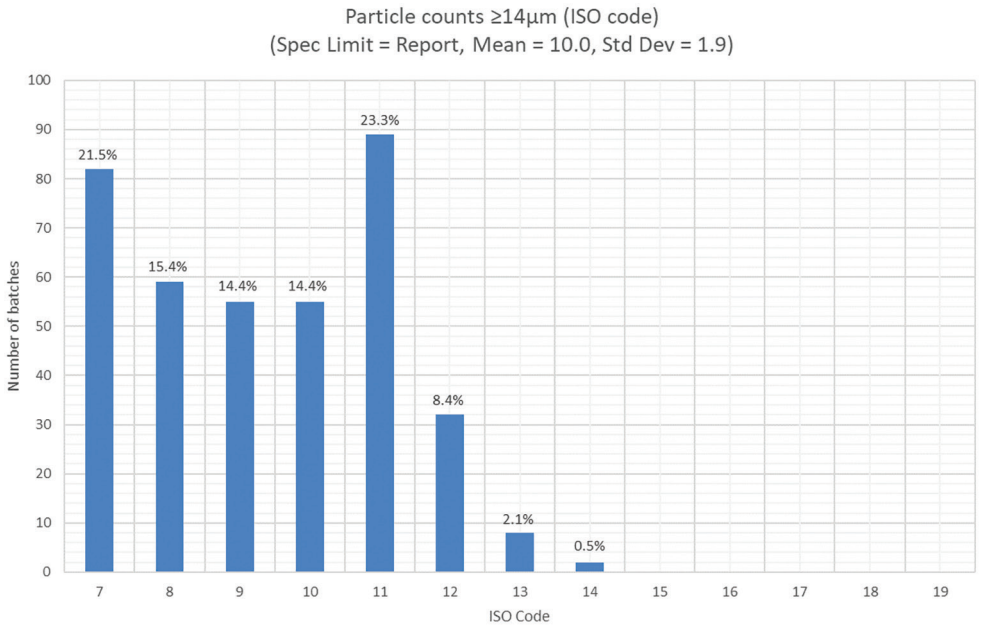


Figure B.69: Particle counts ≥14 µm ISO code (2021)

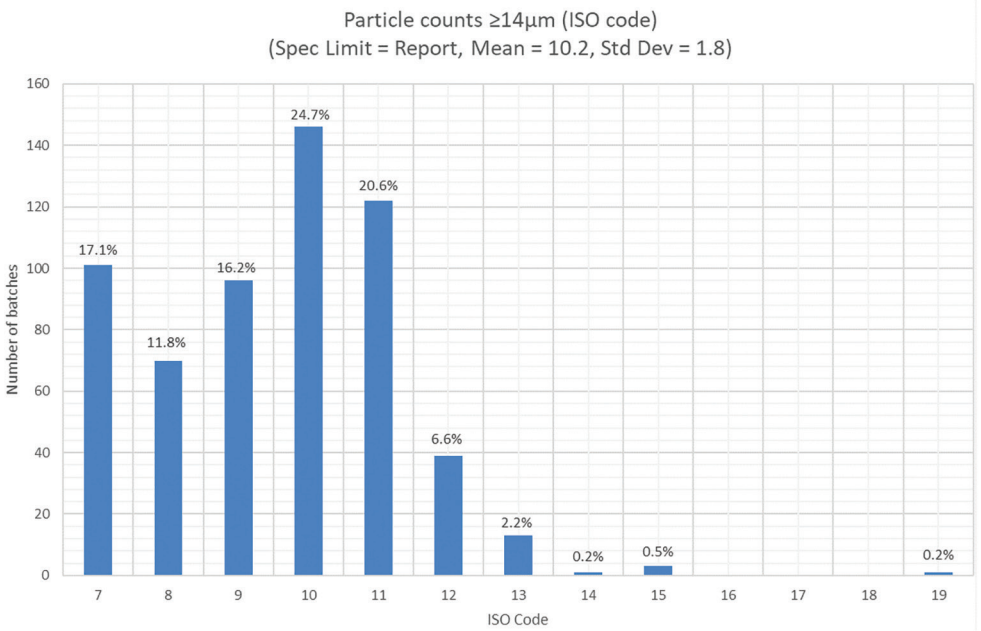


Figure B.70: Particle counts ≥14 µm ISO code (2022)

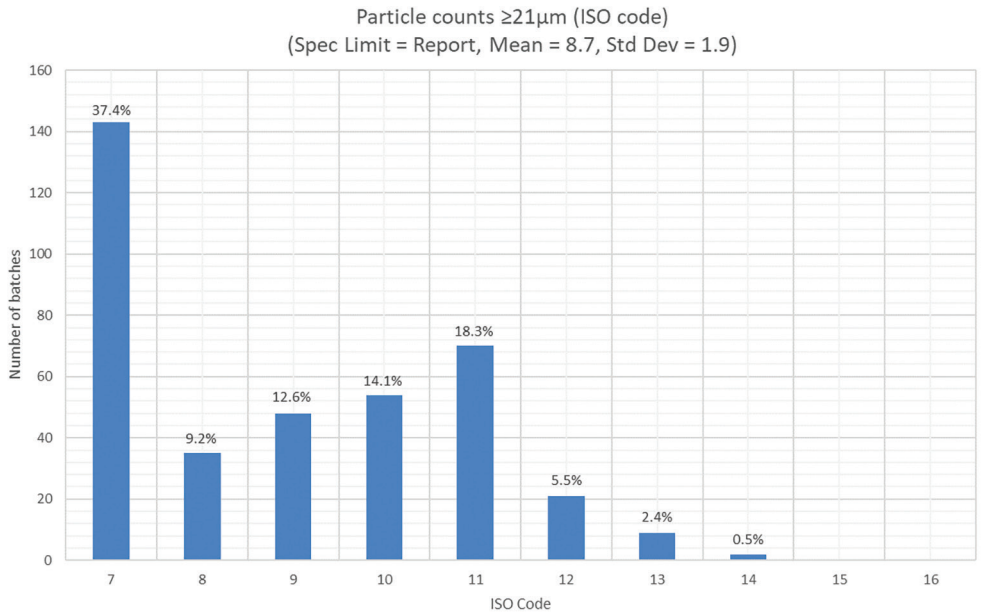


Figure B.71: Particle counts ≥21 µm ISO code (2021)

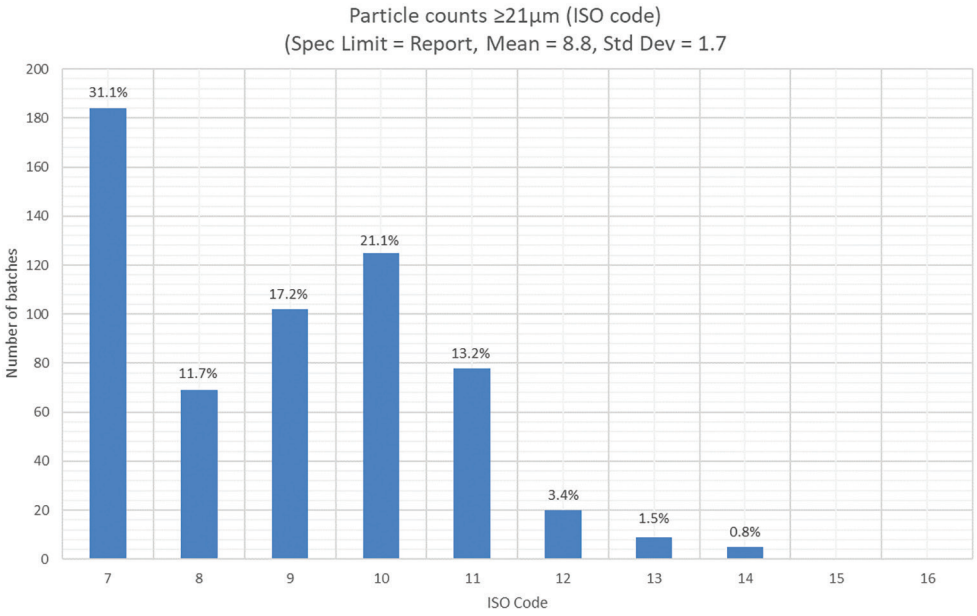


Figure B.72: Particle counts ≥21 µm ISO code (2022)

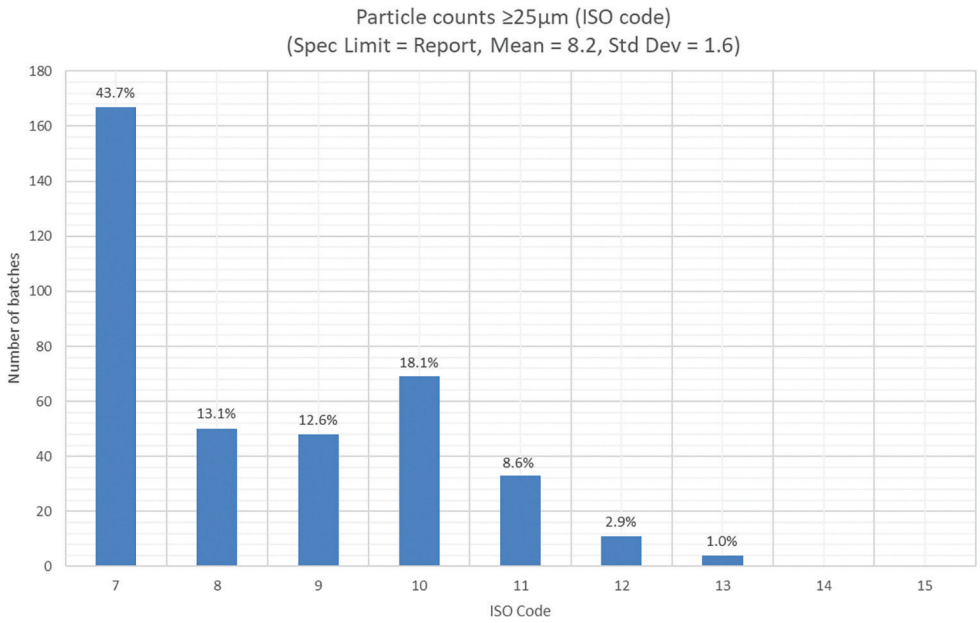


Figure B.73: Particle counts ≥25 µm ISO code (2021)

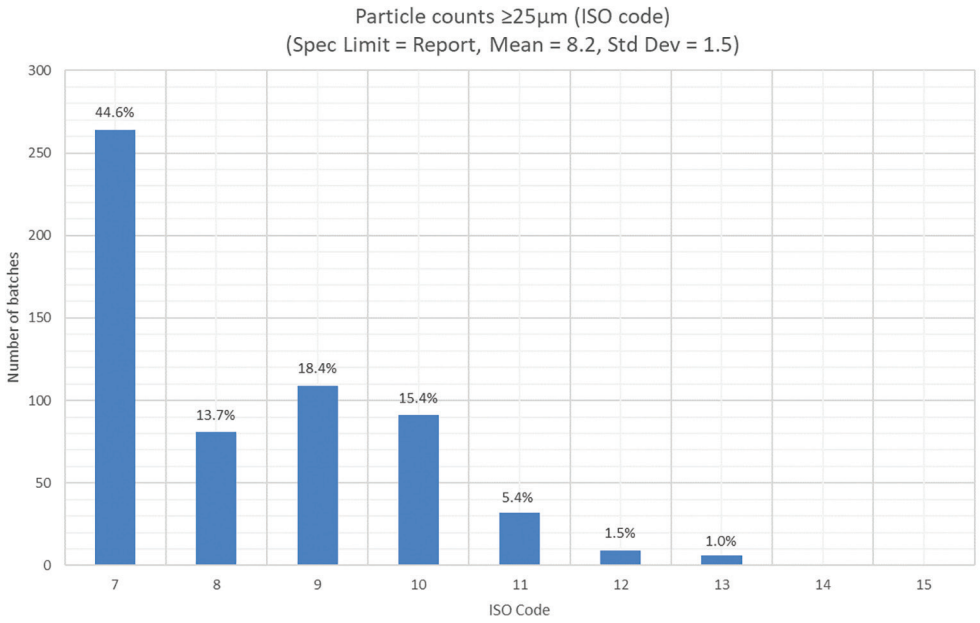


Figure B.74: Particle counts ≥25 µm ISO code (2022)

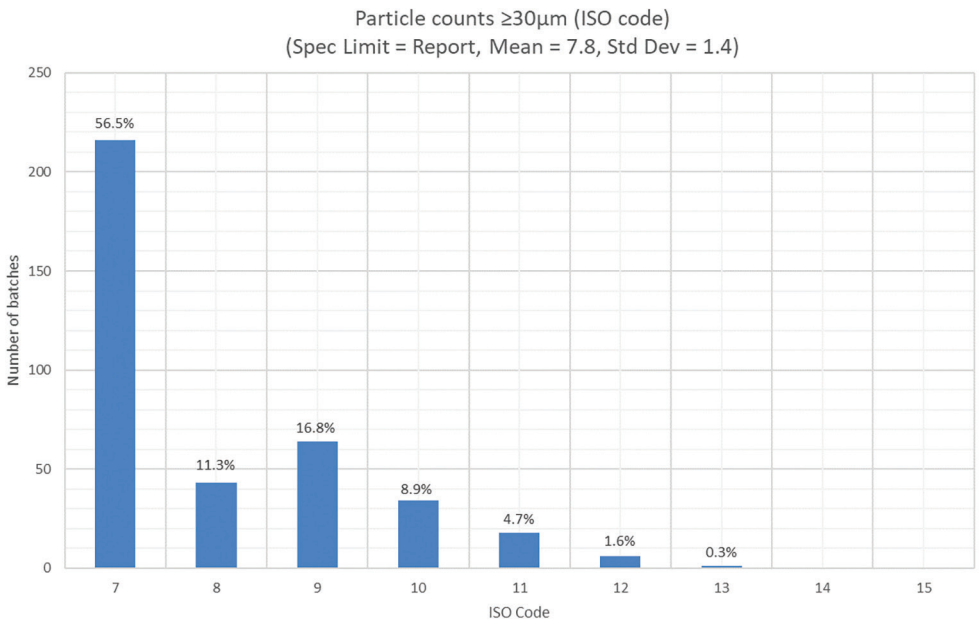


Figure B.75: Particle counts ≥30 µm ISO code (2021)

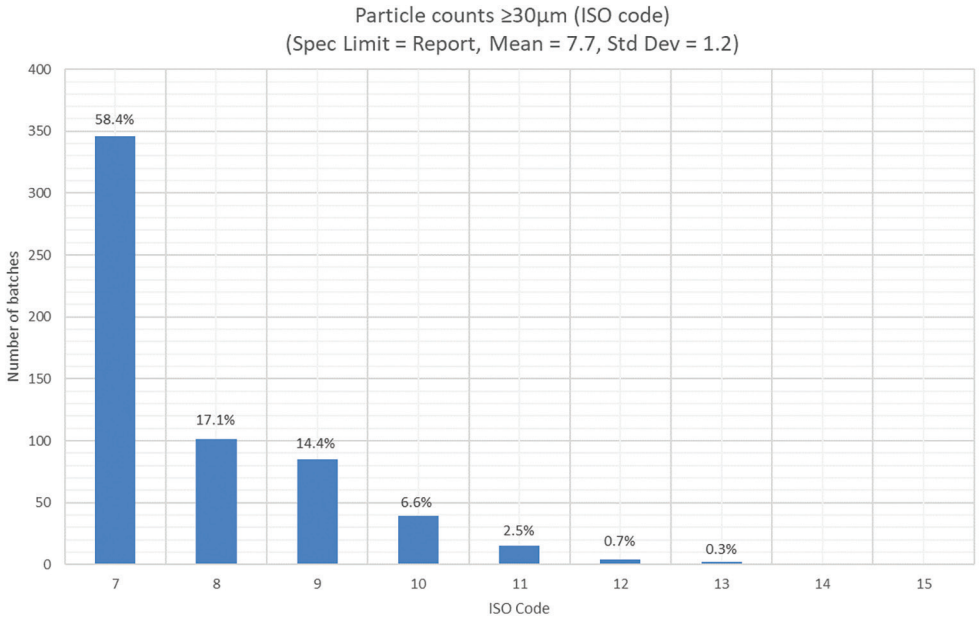


Figure B.76: Particle counts ≥30 µm ISO code (2022)

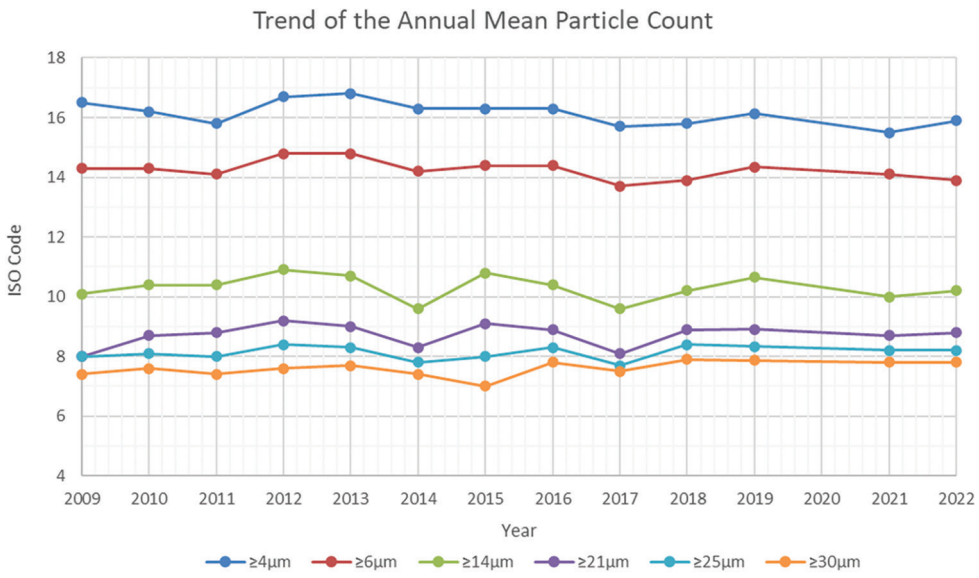


Figure B.77: Particle count trend graph

B.23 NEAR SPECIFICATION LIMIT TREND ANALYSIS

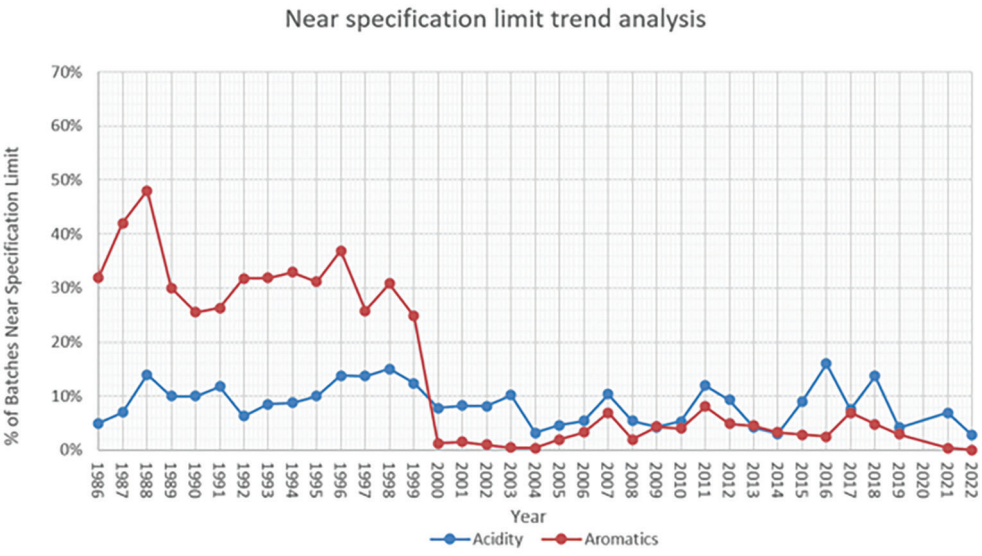


Figure B.78: Near specification trend, acidity and aromatics

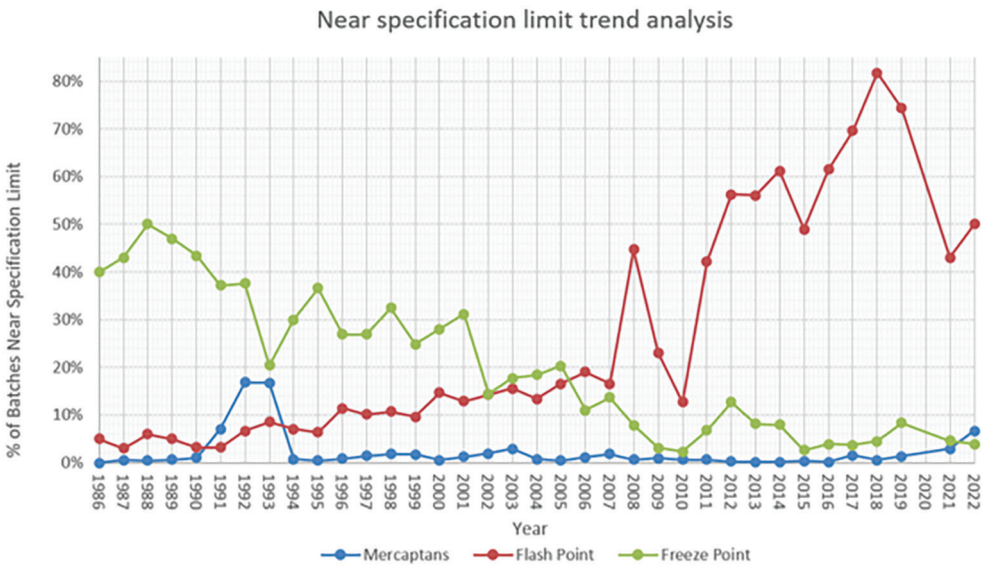


Figure B.79: Near specification trend, mercaptans, flash point and freezing point

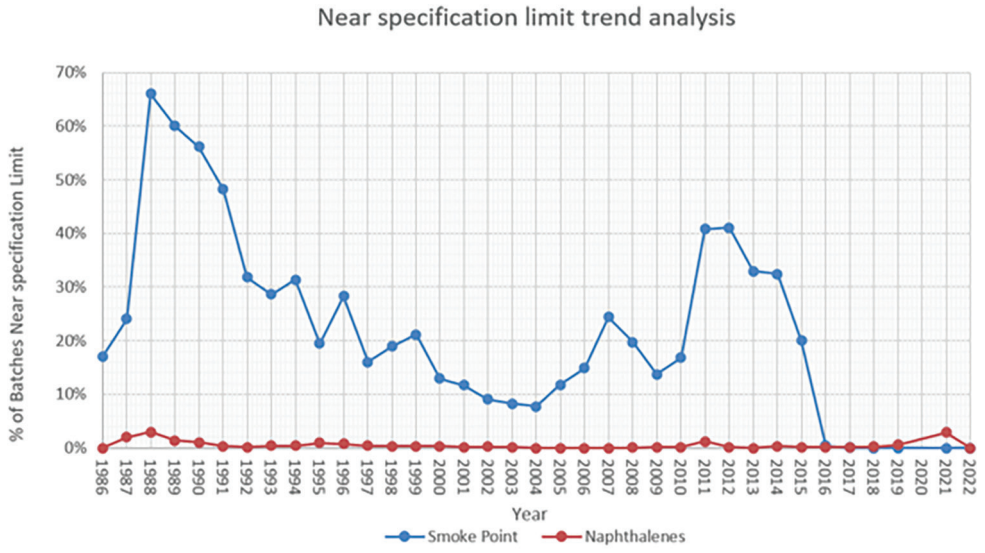


Figure B.80: Near specification trend, smoke point and naphthalenes

APPENDIX C
GLOSSARY OF ABBREVIATIONS AND ACRONYMS

APU	auxiliary power unit
AVTUR	aviation turbine fuel
BOCLE	Ball-on-Cylinder Lubricity Evaluator
CRC	Coordinating Research Council
cSt	centistokes
Def Stan	Defence Standard
DQA/TS	Directorate of Quality Assurance/Technical Support
EI	Energy Institute
FBP	final boiling point
FLC	Fuels and Lubricants Centre
IBP	initial boiling point
MoD	Ministry of Defence (UK)
MQAD	Materials Quality Assurance Directorate
MSEP®	microseparometer
OEM	original equipment manufacturer
SDA	static dissipater additive

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