The quality of aviation fuel available in the United Kingdom

Annual surveys 2009 to 2013

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THE QUALITY OF AVIATION FUEL AVAILABLE IN THE UNITED KINGDOM ANNUAL SURVEYS 2009 TO 2013

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ABSTRACT

This report jointly funded by the Coordinating Research Council and the Energy Institute (EI) and prepared by Intertek contains a summary of the data relating to the specification properties for AVTUR (Jet A-1) supplied in the United Kingdom (UK) during the years 2009 to 2013. The data are expressed in the form of histograms and mean values, which are graphically compared over the period 1986-2013. This report is the thirty-sixth in a series of survey reports.

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1 INTRODUCTION

Surveys relating to the specification properties of aviation turbine fuels supplied in the UK from 1974 onwards have been published annually by The Fuels and Lubricants Centre[2] [1]-[24]. This report covers a similar survey for fuel (Jet A-1) supplied during the period 2009 to 2013 involving 4 327 batches complying with Defence Standard 91-91[25]. Historically, this survey was funded by the UK Ministry of Defence (MoD) in support of their specification development activities. In recent years, the EI has part-funded the work. However, after the 2008 survey was produced, the MoD ceased to fund the activity. In 2014, the EI funded the survey in full, in association with the Coordinating Research Council, and an effort was made to include as much data as possible since the last survey in 2008.

The information contained in this report has been supplied by oil companies and associated test houses for main batches of aviation fuel released during 2009 to 2013. The data are expressed in the form of histograms and mean values, which are graphically compared over the period 1986 to 2013. Arithmetic mean values are not used due to the variation in volume of each fuel batch from which data points are gathered. Instead, the mean values are weighted according to the relative fuel volume associated with each data point.

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

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

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

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

2 RESULTS

The data reported have been abstracted from test certificates, or from electronic data supplied by oil companies, for new batches of AVTUR, either produced in, or imported into, the UK during the period 2009 to 2013. The data for all but four of the specification properties for AVTUR are summarised in tables and figures in the annexes. The data for copper corrosion and thermal stability were not included as the majority of results were identical. Copper corrosion results were typically 1A, with a number of 1B results and thermal stability results were typically a <1 tube rating with no pressure drop. All thermal stability results were reported at 260 °C. Data for electrical conductivity were not included because at the point of testing, the conductivity of many batches was below the specified limits. This is permitted on the condition that static dissipater additive (SDA) is added further downstream [25] to ensure that the conductivity limits are met at the point of delivery into aircraft.

2.1 TABULATED DATA

The tables given in the annexes provide the following information:

Table 3 to Table 7 – specification limits for each property from Defence Standard 91-91 compared to the maxima and minima of the 2009 to 2013 AVTUR data collected.

2.2 HISTOGRAMS AND TREND GRAPHS FOR ANNUAL MEAN RESULTS

Figure 1 to Figure 151 are histograms and trend graphs. The histograms show the number of batches in each frequency class along with the percentage that this represents of the total number of batches included for that year. The trend graphs show the mean results for each property plotted against year for the period 1986 to 2013.

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 histograms (Figure 7 to Figure 11) includes a range of results from >9 to ≤11.

2.3 GRAPHS OF NEAR SPECIFICATION TRENDS FOR AVTUR PRODUCED FROM 1983 TO 2013

For seven specification properties, Figure 152 to Figure 154 show the percentage of batches that have results near the specification limits, plotted against year for the period 1986 to 2013. The properties the figures relate to are listed here.

Figure 152 – acidity, aromatics.

Figure 153 – mercaptan sulfur, flash point, freeze point.

Figure 154 – smoke point, naphthalenes.

3 DISCUSSION

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

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

BOCLE results should be reported for all batches containing more than 95 % hydroprocessed material, of which at least 20 % is severely hydroprocessed. However, it was not possible to establish if a BOCLE test was required for many batches as the refining process was not supplied[3]. No BOCLE results were reported for the batches used in this survey.

3.1 SAMPLE SIZE

Data from 4 327 batches were included in this report which represents 52 273 323 m^3 of AVTUR over the period from the start of 2009 to the end of 2013. This includes more than 100 000 individual test results.

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

3.2 TOTAL ACIDITY

The volume weighted mean value in 2013 was 0.0036 mg KOH/g and this has changed little compared in recent years (Figure 6). There is some evidence of multi-modal distribution. The percentage of batches 'near specification limit' has varied over the period of this report from 4.18 % to 11.93 % with no obvious trend.

3.3 AROMATICS

The volume weighted mean value has varied between 15.7 % v/v to 18.8 % v/v from 2009 to 2013 (Figure 12). The lowest value was in 2009, which was the lowest value since records began in 1986. There was a smaller data set used for the survey for 2009 and 2010 and this may produce some skewing of results. However, the data sets remain very large.

Aircraft operators are often concerned about the problems caused by different batches of fuel having large variations in aromatics. The aromatic content ranged from <5 % v/v to 25.0 % v/v with 99 % of batches in the range 13 % v/v to 25 % v/v.

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

During 2009 and 2010 there were five batches reported as <5 % v/v. The test method used, IP 156, has a scope of 5 % v/v to 99 % v/v aromatic hydrocarbons. For the purposes of this report, the results were recorded as 5 % v/v for the histograms and mean calculations.

3.4 TOTAL SULFUR

The volume weighted mean value from 2009 to 2013 has varied from 0.0047 % m/m to 0.055 % m/m (Figure 18). This is significantly lower than the high value of 0.077 % m/m seen in 2008. There appears to be an upward trend since 1999. However, the mean has been variable in recent years and it is difficult to determine any definite trend. The distribution of sulfur contents appears to show a multimodal distribution.

Defence Standard 91-91 allows several different methods for determining sulfur content. Some laboratories are using methods that can determine the sulfur content to three decimal places, whereas when older equipment/different test methods are used, the result may only be reported to two decimal places. The most common test method used is IP 336 [26] which is reportable to the nearest 0.01 % m/m and the scope minimum is 0.03 % m/m. Therefore, many results are reported for batches with low sulfur contents as '<0.01 % m/m' and some as '<0.03 % m/m'. For the purposes of this report, the results have been recorded without the 'less than' sign (to be consistent with previous surveys). The differing methods mean that it is not possible to accurately determine the number of batches with very low sulfur levels. The methodologies used and the way in which the sulfur content is reported may have an effect on the apparent mean value.

3.5 MERCAPTAN SULFUR

Mercaptan sulfur was reported for approximately three quarters of batches. Mercaptan sulfur is not required to be reported if the Doctor test is negative. A number of test certificates showed the mercaptan sulfur content as '<0.001'. (For the purposes of this survey, these results have always been recorded as 0.001). This may affect the volume weighted mean value, which varied from 0.0007 % mass to 0.0009 % mass during 2009 to 2013 (Figure 24).

3.6 DISTILLATION

The mean value for initial boiling point (IBP) was 148.6 °C and is the lowest recorded since 1986 (Figure 30). The mean values in 2013 for 10 % (167.7 °C) (Figure 36), and 50 % (193.3 °C) (Figure 42) recovered are also the lowest recorded. These three properties show a reducing trend.

The 2013 mean value for 90 % recovered of 233.9 °C is the lowest since 1986 but it is difficult to see a trend as the mean value has been variable in recent years (Figure 48). The final boiling point (FBP) mean has varied between 253.9 °C and 260.8 °C and no trend can be seen (Figure 54).

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

Aviation turbine fuels containing synthesized hydrocarbons in accordance with ASTM D7566 [27] have extended requirements (over ASTM D1655 and Defence Standard 91-91) to ensure a sufficient distillation range[4]. The requirements are T50-T10, minimum of 15 °C; and T90-T10[5], minimum of 40 °C. Of the 1 259 batches in 2013, 10 would not have met the T50-T10 requirement and three would not have met the T90-T10 requirement. The raw data from this report could be used to check that the limits in D7566 are still relevant.

3.7 FLASH POINT

The volume weighted mean value for flash point between 2009 and 2013 has varied from 41.4 °C to 42.6 °C (Figure 60). The 2013 value of 41.4 °C is the lowest recorded since 1986 and there appears to be a reducing trend in the mean flash point since 1991. This trend is becoming less pronounced as the mean values approach the specification limit.

56 % of batches were 'near specification limit' in 2013. There appears to be a rising trend in the number of flash point results near the specification limit. A precision study in 2008 led to the reproducibility of IP 170 being changed from 1.5 °C to 3.2 °C. Although there has been a reduction in the mean and generally more batches near to the specification limit, the large changes seen in Figure 153 are mostly due to the change in reproducibility.

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

3.8 DENSITY

The volume weighted mean for density has varied from 799.9 kg/m^3 to 802.0 kg/m^3 over the period from 2009 to 2013 (Figure 66). The minimum density during 2009 to 2013 was 777.5 kg/m^3. The specification limits are 775 kg/m^3 to 840 kg/m^3.

3.9 FREEZING POINT

The volume weighted mean value for 2013 of –55.0 °C is the lowest value recorded since 1986 and there has been a slow downward trend since this time (Figure 72).

The percentage of batches 'near specification limit' during 2009 to 2013 has varied from 3 % to 12 %. There appears to be a decreasing trend in the number of batches near the specification limit. However, freezing point appears to be a major restraining factor in jet fuel production for some refineries.

Several batches were reported as <-60 °C; these were recorded as -60 °C for the purposes of this report. Two batches had reported freezing points of -46.0 °C which are outside the specification requirement of -47 °C maximum[6].

[4]Although it is difficult to be certain due to the data received not being complete, with regard to refining processes, it is likely that few if any batches included in this survey contained synthetic components.
[5]T10, T50, and T90 are the distillation temperatures at 10 %, 50 %, and 90 % recovered respectively.
[6]No further information was received on the two batches outside the specification. However, after discussion with the producer it is thought very unlikely that out of specification fuel reached an aircraft. It is likely that the batch was blended to ensure that the final product was fit for use.

3.10 KINEMATIC VISCOSITY

The volume weighted mean for 2013 was 3.66 cSt, which is the lowest recorded since 1986 (Figure 78). There appears to be a reducing trend in mean viscosity and there has been a significant reduction since 2010.

The specification limit is 8 cSt maximum at -20 °C. However, it should be noted that most aircraft engines are certified at 12 cSt maximum at -40 °C[7]. This is approximately equivalent to 5.5 cSt at -20 °C. There were two batches in 2009 that exceeded 5.5 cSt in 2009 and none from 2010 to 2013.

3.11 SPECIFIC ENERGY

The volume weighted mean was 43.24 MJ/kg in 2013 and represents little change compared to recent years. Figure 84 shows no particular trend in mean value. Results are almost all between 43.0 MJ/kg and 43.5 MJ/kg. The specification minimum is 42.80 MJ/kg.

3.12 SMOKE POINT

The volume weighted mean for 2013 was 23.3 mm. The smoke point specification limit is 19 mm minimum.

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

3.13 NAPHTHALENES

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

The mean for 2013 was 1.16 % vol, the lowest ever recorded since records began in 1986. There appears to be a downward trend since 1988 (Figure 96). The specification limit is 3 % vol maximum.

3.14 EXISTENT GUM

For more than 90 % of batches from 2009 to 2013, the existent gum results were reported as 0, <1, or 1 mg/100ml. For results reported as 0 or <1, a value of 1 has been recorded in the histograms. The 2013 mean value was 1.0 mg/100ml as shown in Figure 101. The precision for existent gum is very poor; it is likely that all batches contain virtually no gum and

[7]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.

the range of results (up to a maximum of 6 mg/100ml) is due to the test precision. The vast majority of the results are well below the 7 mg/100ml maximum specification limit. There is no significant trend in mean value for existent gum.

3.15 MICROSEPAROMETER

The 2013 mean MSEP value of 94.5 has changed little compared to the previous few years (Figure 108).

The Defence Standard 91-91 limitsfor MSEP rating is a minimum of 85 without SDA, or 70 with SDA due to the over sensitivity of the test method to SDA (Stadis 450). Some MSEP values during 2011, 2012, and 2013 were reported outside the specification limits. The reported failures may not be at the point of manufacture and downstream of this point a low MSEP is not used as the sole reason for rejection of a fuel.

3.16 PARTICULATE CONTAMINATION

This is a relatively new requirement for Defence Standard 91-91 with a maximum limit of 1 mg/l. The 2013 volume weighted mean value of 0.29 is similar to that recorded in recent years (Figure 114). A number of batches did not include results for this property. Most of these batches were imported fuel and it is assumed that this testing was carried out at point of manufacture as required by the specification. No results outside the specification limit were reported.

3.17 SAYBOLT COLOUR

This is a relatively new requirement for Defence Standard 91-91. The 2013 volume weighted mean value is 26.5 and changed little over the period from 2009 to 2013 (Figure 120). A number of batches did not include results for this property. Most of these batches were thought to be imported fuel and it is assumed that this testing was carried out at point of manufacture as required by the specification.

3.18 PARTICLE COUNTS

Particle counts are recorded for the first time in this survey. For ease of producing histograms, ISO codes [28] have been used to indicate particle numbers[8]. Histograms show the distribution of ISO codes for ≥4 µm, ≥6 µm, ≥14 µm, ≥21 µm, ≥25 µm, and ≥30 µm channels. For low particle counts (and low ISO codes) repeatability is poor and many labs report ISO codes below 7 as '<7'. For the purposes of this report any value of less than 7 was recorded as 7.

The mean values are shown in Figure 151 over the period of 2009 to 2013. No trends are apparent. No specification limits for this property have been set at this time.

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

3.19 BOCLE

There were no BOCLE results reported from 2009 to 2013.

3.20 NEAR SPECIFICATION TRENDS

Figure 152 to Figure 154 are graphs showing the percentage of batches with test results near the specification limit, against year, for seven specification properties.

The properties with the highest percentage of batches with results near the specification limit in 2013 were flash point (56 %) and smoke point (33 %). It should be noted that the new precision for flash point (IP 170) has significant effects on the number of batches near specification limit as mentioned in 3.7.

4 SUMMARY OF CHANGES AND TRENDS

4.1 TREND DATA

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

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

4.2 SIGNIFICANT CHANGES IN 2013

Table 2: Significant changes in mean values

Property	Change
Distillation, IBP	Down 2.2 °C since 2009 (mean is at the lowest level since records began in 1986)
Distillation, 10 % recovered	Down 3.4 °C since 2010 (mean is at the lowest level since records began in 1986)
Distillation, 50 % recovered	Down 4.0 °C since 2010 (mean is at the lowest level since records began in 1986)
Flash point	Down 1.2 °C since 2010 (mean is at the lowest level since records began in 1986)
Freezing point	Down 3.1 °C since 2011 (mean is at the lowest level since records began in 1986)
Viscosity	Down 0.25 mm^2/s since 2010 (mean is at the lowest level since records began in 1986)
Naphthalenes	Down 0.37 % volume since 2010 (mean is at the lowest level since records began in 1986)

5 REFERENCES

[1] Various 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] Specification Defence Standard 91-91. *Turbine fuel, aviation kerosine type, Jet A-1, NATO* code: F-35, JSD: AVTUR. Issued by UK Defence Standardisation, Kentigern House, 65 Brown Street, Glasgow G2 8EX (www.dstan.mod.uk).
[26] IP 336**:** *Petroleum products - Determination of sulfur content – Energy-dispersive-X-ray fluorescence method.* https://publishing.energyinst.org.
[27] ASTM D7566, *Standard specification for aviation turbine fuel containing synthesized hydrocarbons*. www.ASTM.org.
[28] BS ISO 4406, *Hydraulic fluid power – fluids – Method for coding the level of contamination by solid particles*.

ANNEX A
RESULTS SUMMARIES

A.1 2009 - DATA FROM 608 BATCHES OF JET FUEL REPRESENTING 7 197 709 M³

Table 3: Minima and maxima for 2009 data and specification limits

Method	Def Stan 91-91 specification limits		Results summary 2009		
	Min	Max	Min	Max	Mean
Total acidity, mg KOH/g	-	0.015	0	0.015	0.0040
Aromatics, % volume	-	25.0[8]	5[9]	24.0	15.7
Total sulfur, % mass	-	0.30	0.001	0.248	0.052
Mercaptan sulfur, % mass	-	0.0030	0.0001	0.0027	0.0009
Distillation IBP, °C	Report		137.6	168.9	150.8
10 % recovery, °C	-	205.0	161.0	184.3	170.6
50 % recovery, °C	Report		184.2	210.6	196.4
90 % recovery, °C	Report		211.0	247.6	235.0
FBP, °C	-	300.0	236.2	279.6	256.9
Flash point, °C	38.0	-	38.0	51.6	42.0
Density @ 15 °C, kg/m³	775.0	840.0	789.1	817.8	801.9
Freezing point, °C	-	-47.0	-69.0[10]	-47.5	-53.1
Viscosity @ -20 °C, mm²/s	-	8.00	3.168	5.822	3.84
Specific energy, Net MJ/kg	42.80	-	43.02	43.47	43.22
Smoke point, mm	19.0	-	20.0	27.0	23.21
Naphthalenes, % volume	-	3.00	0.17	2.87	1.52
Existent gum, mg/100ml	-	7	0	5	1.12
MSEP	85 (70 with SDA)	-	71	100	94.4
BOCLE, mm	-	0.85	n/a	n/a	n/a
Particulate, mg/l	-	1.0	0.00	1.00	0.27
Colour	Report		12	30	26.6
Particle count,					
≥4 µm	Report		12	22	16.5
≥6 µm	Report		8	21	14.3
≥14 µm	Report		7	16	10.1
≥21 µm	Report		7	13	8.0
≥25 µm	Report		7	12	7.4
≥30 µm	Report		7	11	7.1

[8]The limit is 26.5 if using IP 436. All results have been converted to IP 156 equivalent data.
[9]The scope of IP 156 is for fuels with aromatics of 5 % and above. A number of batches were reported as <5 %. Therefore, the true minimum is not known.
[10]One result of less than <-60° was recorded. Therefore, a lower minimum freezing point than reported in Table 3 is possible.

A.2 2010 - DATA FROM 491 BATCHES OF JET FUEL REPRESENTING 6 713 391 M³

Table 4: Minima and maxima for 2010 data and specification limits

Method	Def Stan 91-91 specification limits		Results summary 2010		
	Min	Max	Min	Max	Mean
Total acidity, mg KOH/g	-	0.015	0.001	0.015	0.0048
Aromatics, % volume	-	25.0[11]	5[12]	25.0	18.8
Total sulfur, % mass	-	0.30	0	0.29	0.047
Mercaptan sulfur, % mass	-	0.0030	0.0001	0.0028	0.0009
Distillation IBP, °C	Report		140.0	164.3	151.1
10 % recovery, °C	-	205.0	161.2	189.2	171.1
50 % recovery, °C	Report		185.0	212.3	197.3
90 % recovery, °C	Report		213.1	246.6	235.6
FBP, °C	-	300.0	235.4	282.5	257.7
Flash point, °C	38.0	-	38.0	50.9	42.6
Density @ 15 °C, kg/m³	775.0	840.0	792.1	811.5	802.0
Freezing point, °C	-	-47.0	-69.8[13]	-47.6	-53.7
Viscosity @ -20 °C, mm²/s	-	8.00	2.365	5.251	3.91
Specific energy, Net MJ/kg	42.80	-	43.00	43.92	43.19
Smoke point, mm	19.0	-	19.0	27.0	22.52
Naphthalenes, % volume	-	3.00	0.25	2.84	1.53
Existent gum, mg/100ml	-	7	0	6	1.10
MSEP	85 (70 with SDA)	-	72	100	94.0
BOCLE, mm	-	0.85	n/a	n/a	n/a
Particulate, mg/l	-	1.0	0.00	1.00	0.26
Colour	Report		16	30	27.4
Particle count,					
≥4 µm	Report		12	22	16.2
≥6 µm	Report		7	21	14.3
≥14 µm	Report		7	17	10.4
≥21 µm	Report		7	14	8.7
≥25 µm	Report		7	13	8.1
≥30 µm	Report		7	11	7.6

[11]The limit is 26.5 if using IP 436. All results have been converted to IP 156 equivalent data.
[12]The scope of IP 156 is for fuels with aromatics of 5 % and above. One batch was reported as <5 %. Therefore, the true minimum is not known.
[13]One result of less than <-60° was recorded. Therefore, a lower minimum freezing point than reported in Table 4 is possible.

A.3 2011 - DATA FROM 765 BATCHES OF JET FUEL REPRESENTING 9 336 574 M³

Table 5: Minima and maxima for 2011 data and specification limits

Method	Def Stan 91-91 specification limits		Results summary 2011		
	Min	Max	Min	Max	Mean
Total acidity, mg KOH/g	-	0.015	0.000	0.015	0.0044
Aromatics, % volume	-	25.0[14]	8.4	24.1	18.6
Total sulfur, % mass	-	0.30	0.001	0.210	0.047
Mercaptan sulfur, % mass	-	0.0030	0.0001	0.0030	0.0008
Distillation IBP, °C	Report		140.9	186.4	150.7
10 % recovery, °C	-	205.0	158.5	195.5	168.9
50 % recovery, °C	Report		183.6	230.0	194.9
90 % recovery, °C	Report		210.0	260.0	234.7
FBP, °C	-	300.0	225.7	296.0	253.9
Flash point, °C	38.0	-	38.0	50.5	42.0
Density @ 15 °C, kg/m³	775.0	840.0	786.9	816.3	801.9
Freezing point, °C	-	-47.0	-75.0	-47.6	-51.9
Viscosity @ -20 °C, mm²/s	-	8.00	2.073	5.243	3.76
Specific energy, Net MJ/kg	42.80	-	42.83	43.42	43.21
Smoke point, mm	19.0	-	19.0	28.0	22.89
Naphthalenes, % volume	-	3.00	0.14	2.99	1.48
Existent gum, mg/100ml	-	7	1	6	1.11
MSEP	85 (70 with SDA)	-	54	100	94.8
BOCLE, mm	-	0.85	n/a	n/a	n/a
Particulate, mg/l	-	1.0	0.00	1.00	0.23
Colour	Report		16	30	26.8
Particle count,					
≥4 µm	Report		12	22	15.8
≥6 µm	Report		10	21	14.1
≥14 µm	Report		7	16	10.4
≥21 µm	Report		7	16	8.8
≥25 µm	Report		7	15	8.0
≥30 µm	Report		7	13	7.4

[14]The limit is 26.5 if using IP 436. All results have been converted to IP 156 equivalent data.

A.4 2012 - DATA FROM 1 204 BATCHES OF JET FUEL REPRESENTING 14 104 040 M³

Table 6: Minima and maxima for 2012 data and specification limits

Method	Def Stan 91-91 specification limits		Results summary 2012		
	Min	Max	Min	Max	Mean
Total acidity, mg KOH/g	-	0.015	0.001	0.015	0.0038
Aromatics, % volume	-	25.0[15]	8.2	24.8	17.4
Total sulfur, % mass	-	0.30	0.001	0.253	0.055
Mercaptan sulfur, % mass	-	0.0030	0.0000	0.0027	0.0008
Distillation IBP, °C	Report		140.5	163.6	149.4
10 % recovery, °C	-	205.0	159.5	188.0	168.3
50 % recovery, °C	Report		178.7	211.3	194.7
90 % recovery, °C	Report		210.3	256.3	236.2
FBP, °C	-	300.0	235.9	286.1	260.8
Flash point, °C	38.0	-	38.0	51.5	41.5
Density @ 15 °C, kg/m³	775.0	840.0	784.9	817.1	801.2
Freezing point, °C	-	-47.0	-71.6	-46.0	-54.2
Viscosity @ -20 °C, mm²/s	-	8.00	2.963	4.762	3.75
Specific energy, Net MJ/kg	42.80	-	43.00	43.51	43.23
Smoke point, mm	19.0	-	19.0	29.0	23.17
Naphthalenes, % volume	-	3.00	0.19	2.87	1.42
Existent gum, mg/100ml	-	7	1	6	1.09
MSEP	85 (70 with SDA)	-	53	100	94.0
BOCLE, mm	-	0.85	n/a	n/a	n/a
Particulate, mg/l	-	1.0	0.00	1.00	0.27
Colour	Report		12	30	26.6
Particle count,					
≥4 µm	Report		12	22	16.7
≥6 µm	Report		10	22	14.8
≥14 µm	Report		7	19	10.9
≥21 µm	Report		7	18	9.2
≥25 µm	Report		7	16	8.4
≥30 µm	Report		7	15	7.6

[15]The limit is 26.5 if using IP 436. All results have been converted to IP 156 equivalent data.

A.5 2013 - DATA FROM 1 259 BATCHES OF JET FUEL REPRESENTING 14 921 609 M³

Table 7: Minima and maxima for 2013 data and specification limits

Method	Def Stan 91-91 specification limits		Results summary 2013		
	Min	Max	Min	Max	Mean
Total acidity, mg KOH/g	-	0.015	0.000	0.015	0.0036
Aromatics, % volume	-	25.0[16]	8.2	25.0	17.9
Total sulfur, % mass	-	0.30	0.0002	0.2000	0.048
Mercaptan sulfur, % mass	-	0.0030	0.0001	0.0026	0.0007
Distillation IBP, °C	Report		134.3	165.7	148.6
10 % recovery, °C	-	205.0	158.6	180.6	167.7
50 % recovery, °C	Report		171.1	208.1	193.3
90 % recovery, °C	Report		193.7	252.2	233.9
FBP, °C	-	300.0	230.3	284.2	258.0
Flash point, °C	38.0	-	38.0	49.0	41.4
Density @ 15 °C, kg/m³	775.0	840.0	777.5	814.8	799.9
Freezing point, °C	-	-47.0	-77.1	-46.0	-55.0
Viscosity @ -20 °C, mm²/s	-	8.00	2.477	4.767	3.66
Specific energy, Net MJ/kg	42.80	-	43.00	43.56	43.24
Smoke point, mm	19.0	-	19.5	29.0	23.34
Naphthalenes, % volume	-	3.00	0.04	2.56	1.16
Existent gum, mg/100ml	-	7	0	5	1.08
MSEP	85 (70 with SDA)	-	65	100	94.5
BOCLE, mm	-	0.85	n/a	n/a	n/a
Particulate, mg/l	-	1.0	0.00	1.00	0.29
Colour	Report		12	30	26.5
Particle count,					
≥4 µm	Report		12	22	16.8
≥6 µm	Report		10	21	14.8
≥14 µm	Report		7	18	10.7
≥21 µm	Report		7	16	9.0
≥25 µm	Report		7	16	8.3
≥30 µm	Report		7	15	7.7

[16]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

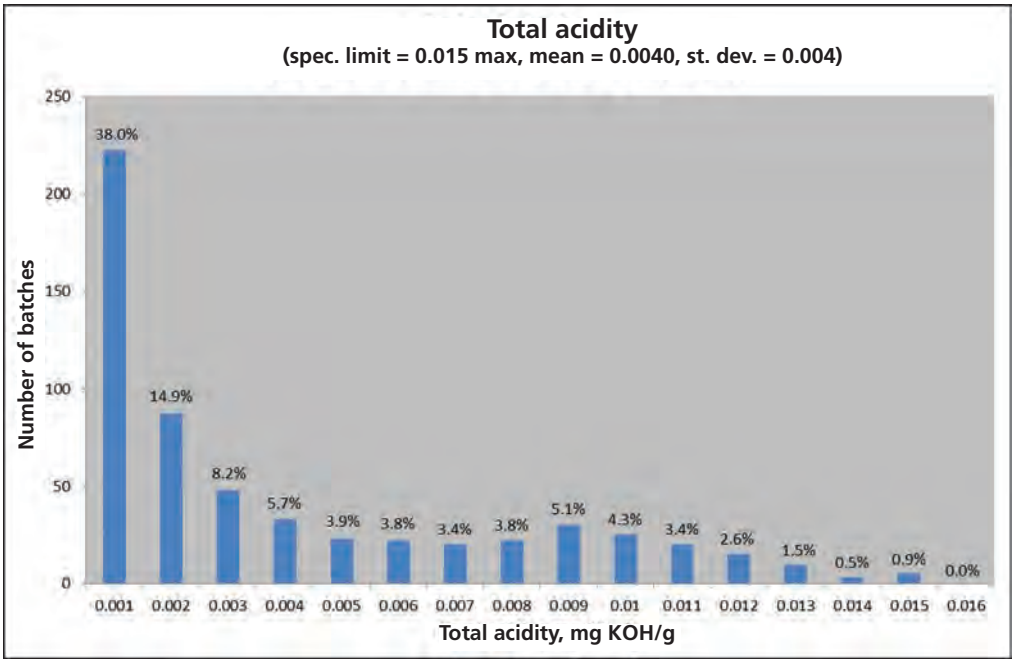

Figure 1: Total acidity histogram 2009

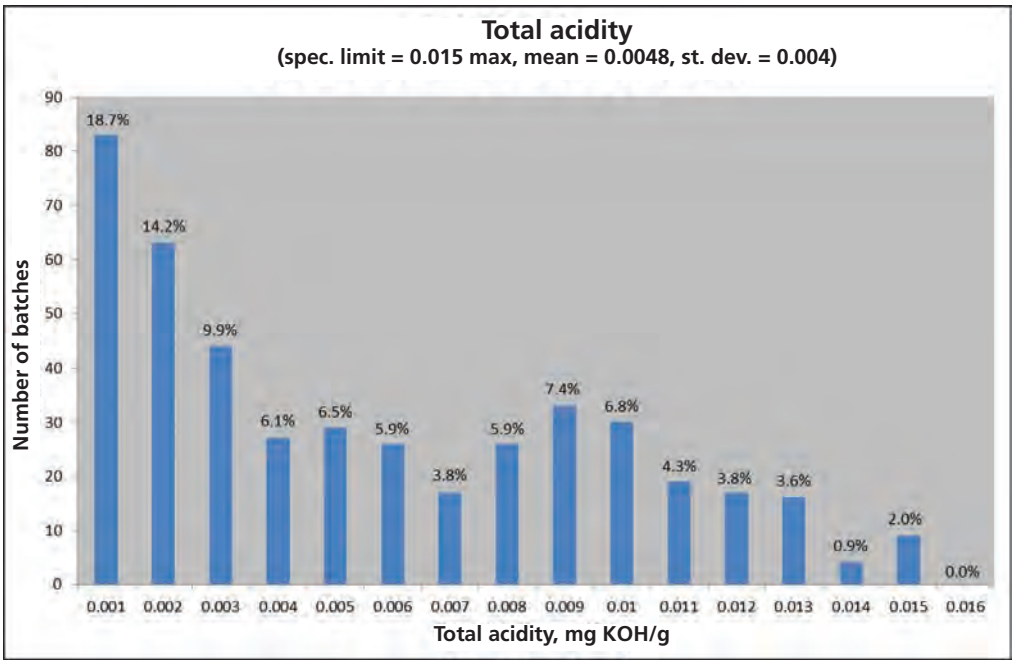

Figure 2: Total acidity histogram 2010

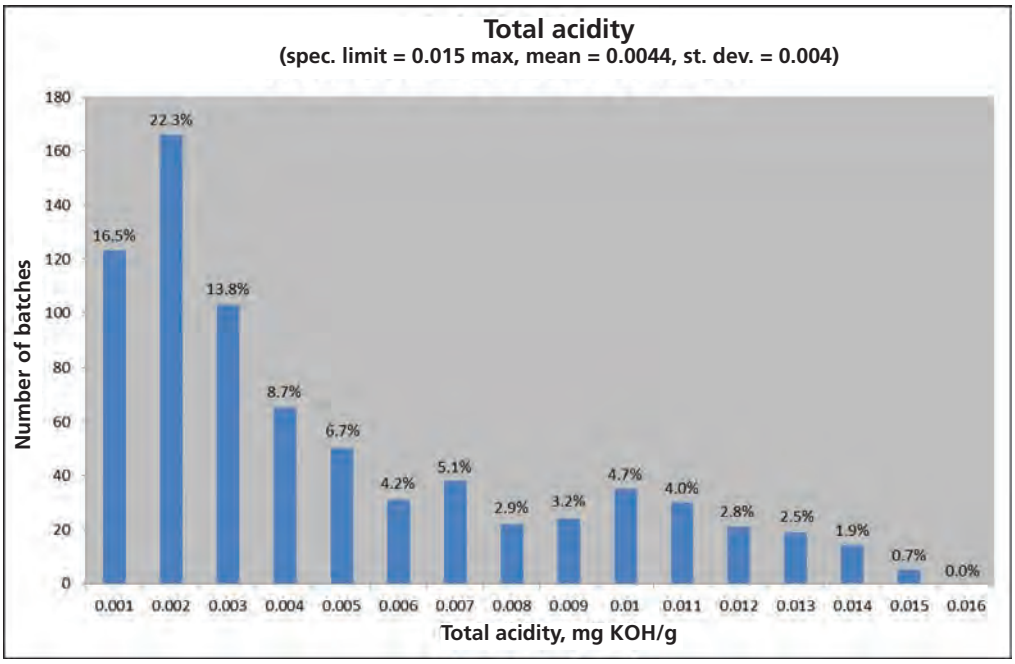

Figure 3: Total acidity histogram 2011

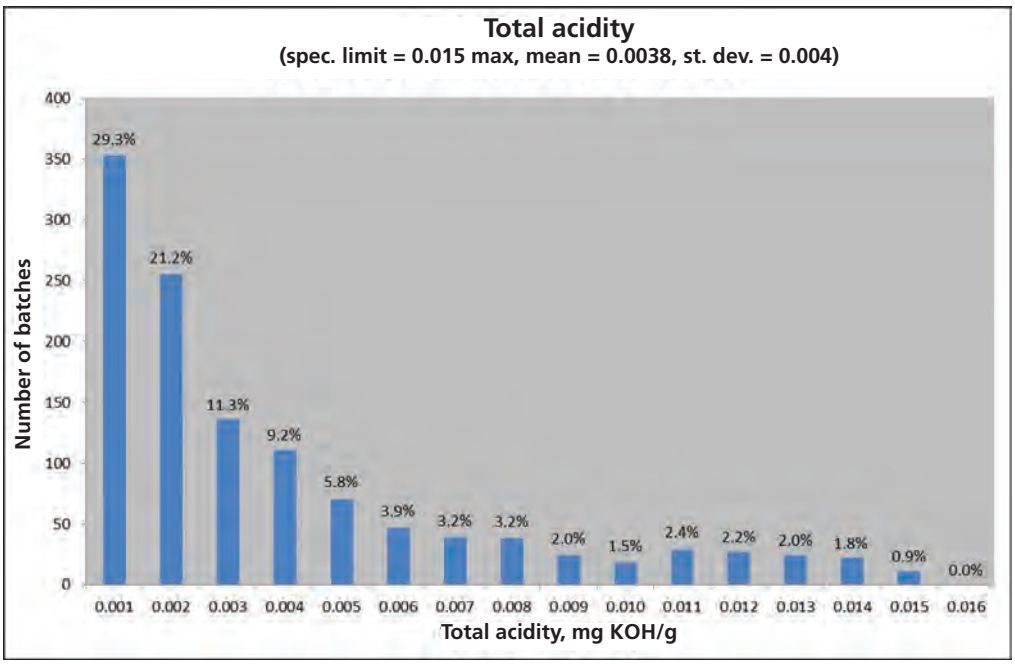

Figure 4: Total acidity histogram 2012

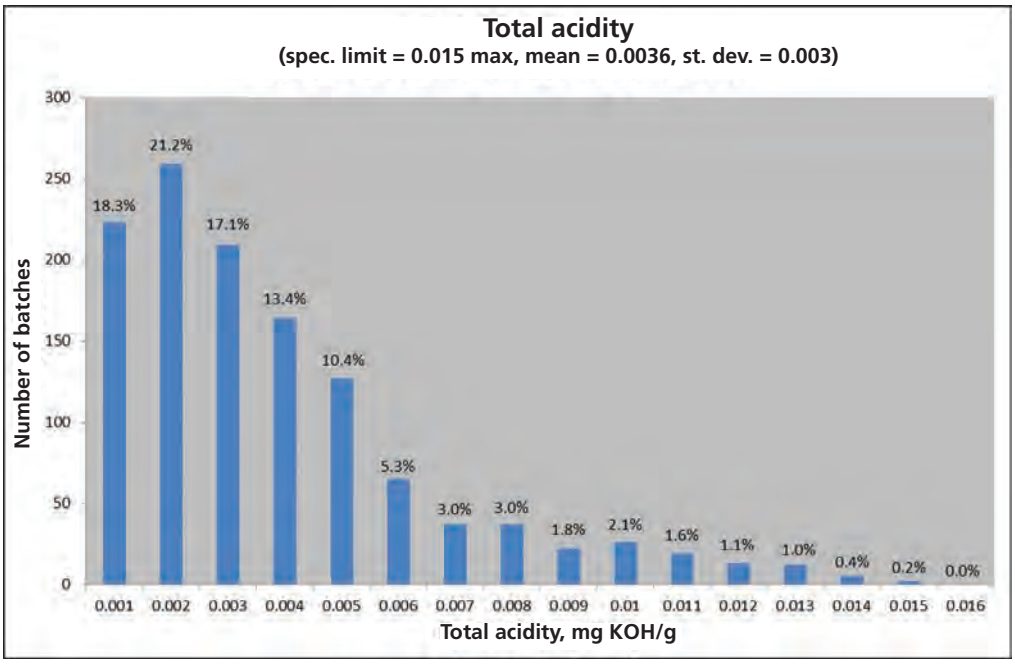

Figure 5: Total acidity histogram 2013

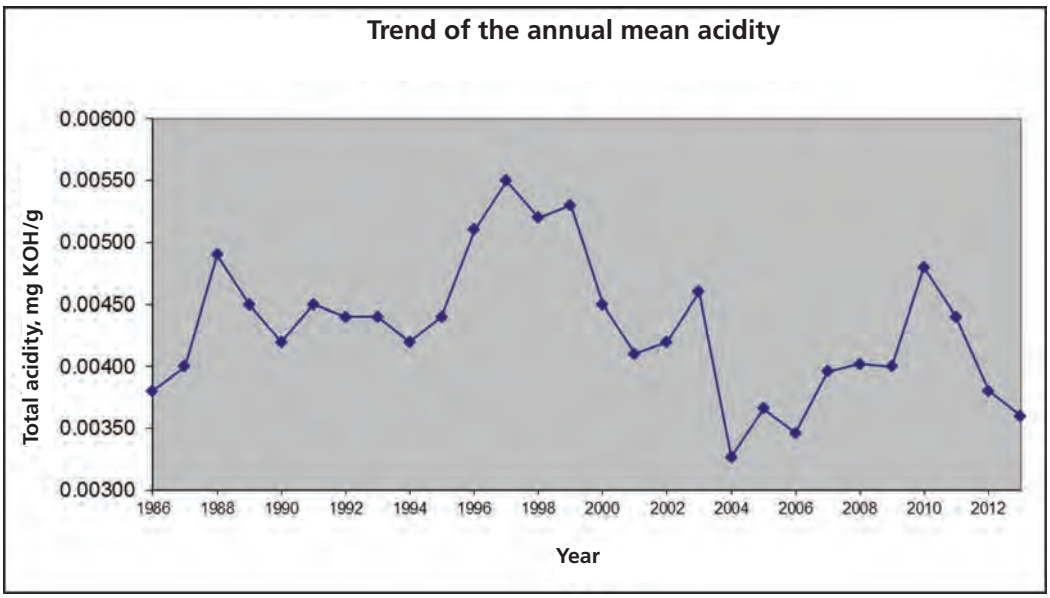

Figure 6: Total acidity trend graph

B.2 AROMATICS

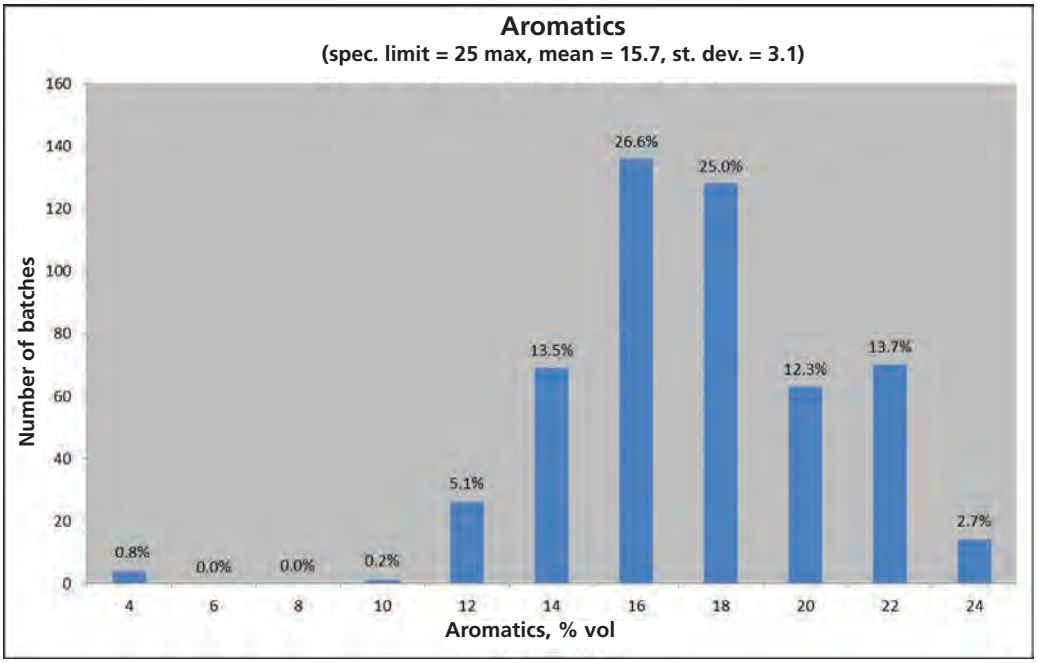

Figure 7: Aromatics histogram 2009

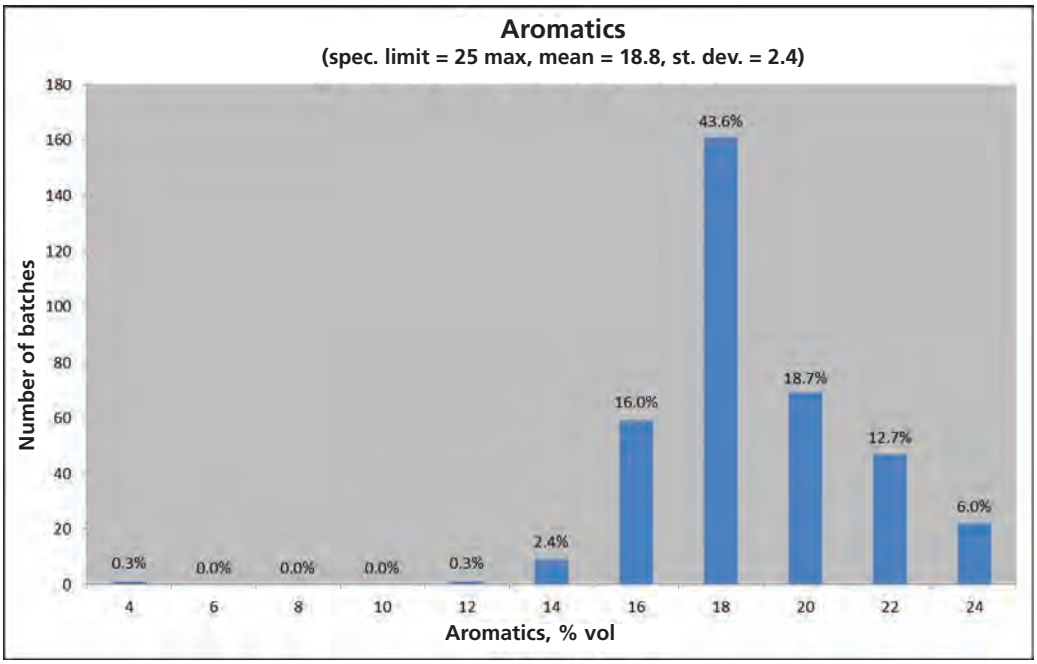

Figure 8: Aromatics histogram 2010

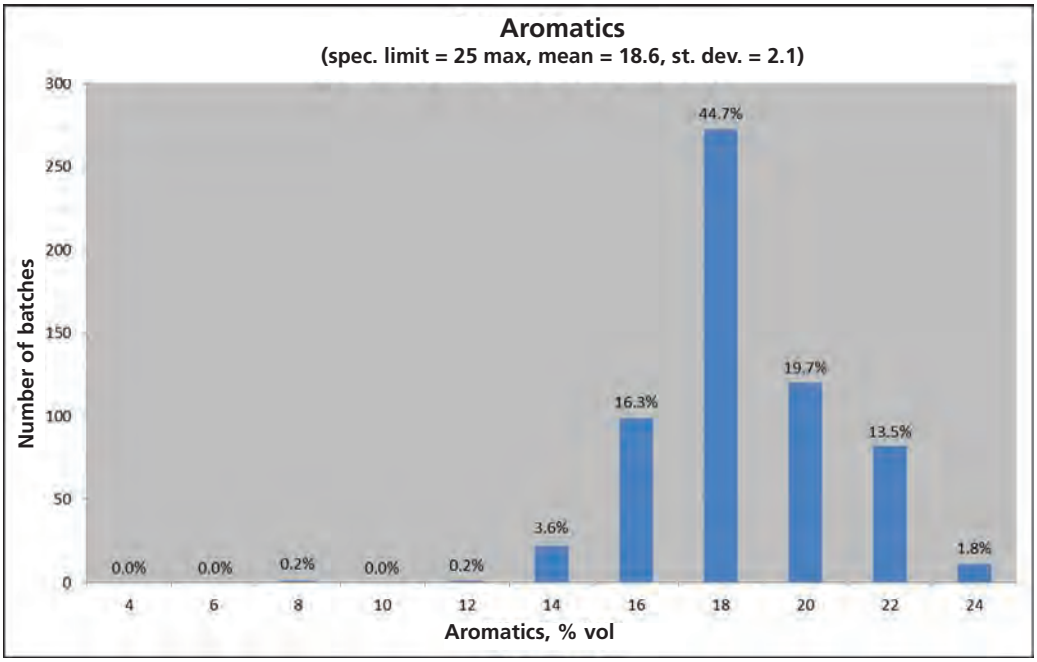

Figure 9: Aromatics histogram 2011

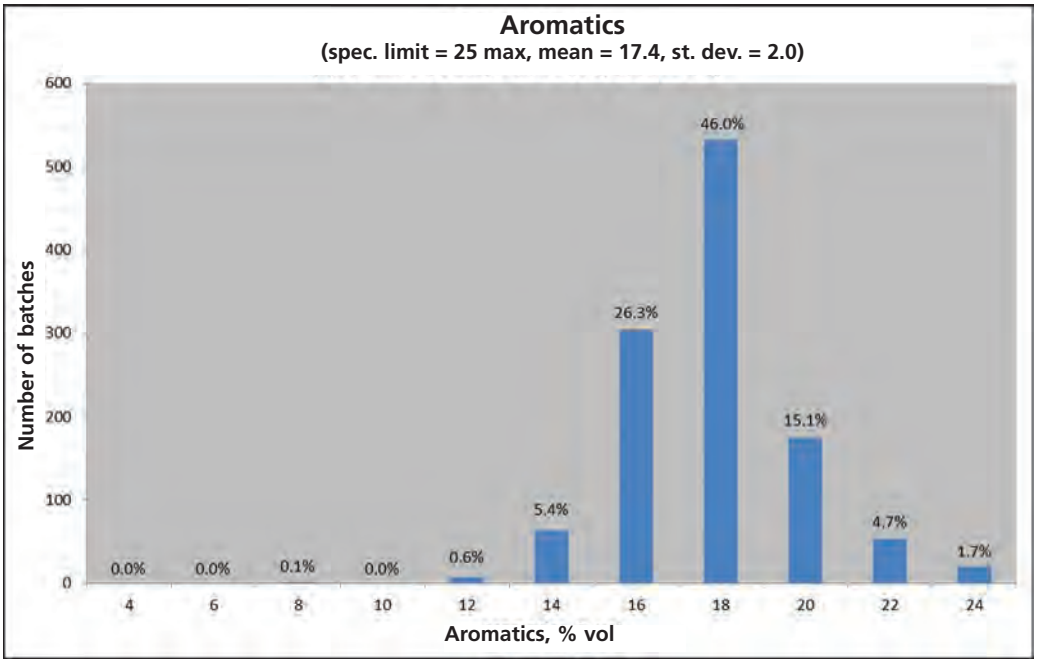

Figure 10: Aromatics histogram 2012

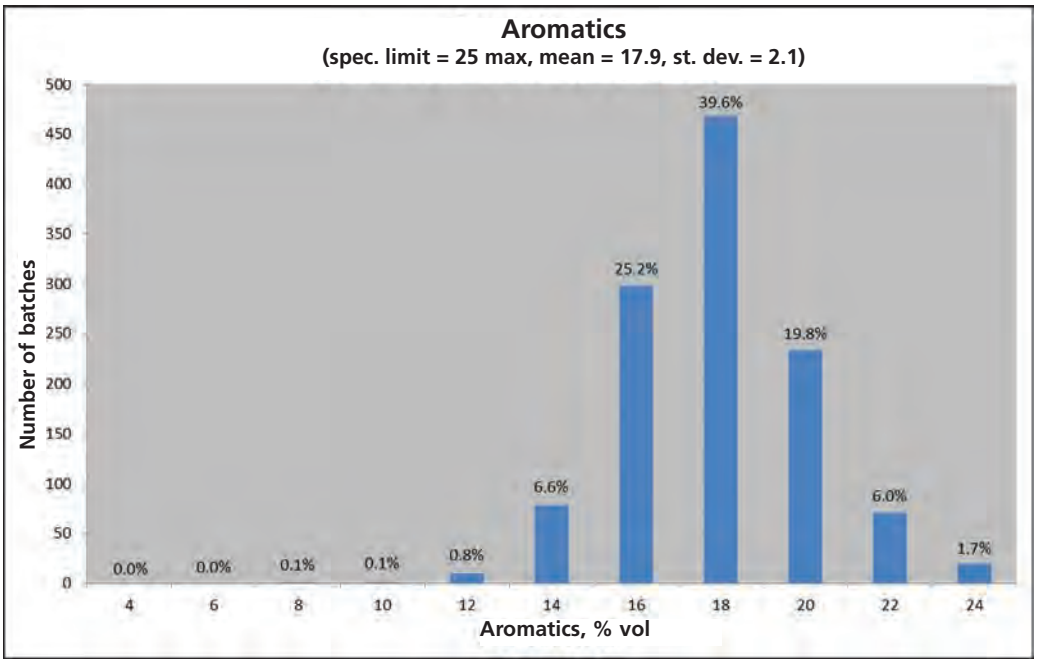

Figure 11: Aromatics histogram 2013

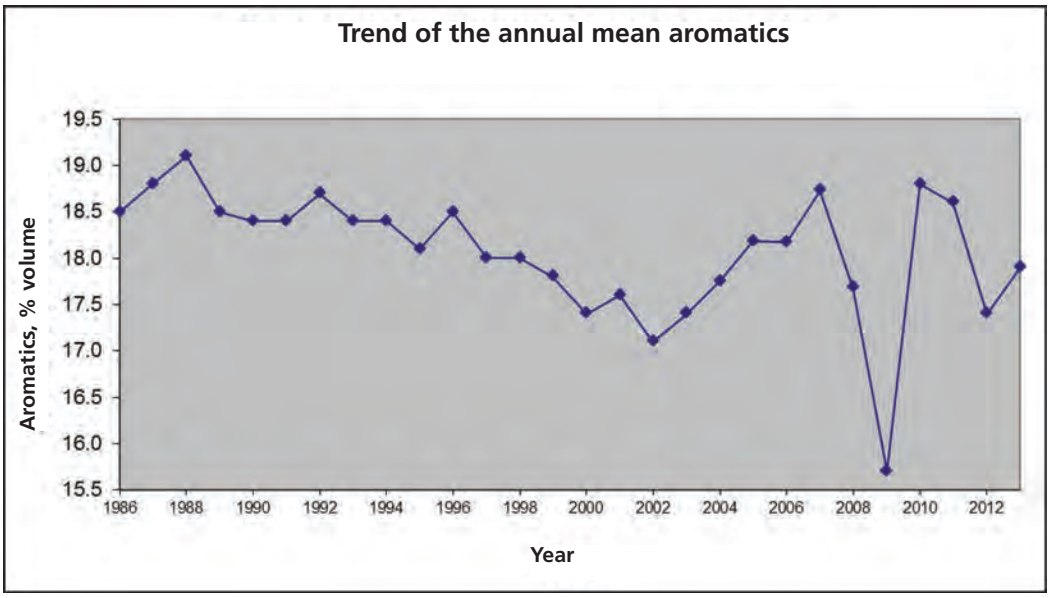

Figure 12: Aromatics trend graph

B.3 TOTAL SULFUR

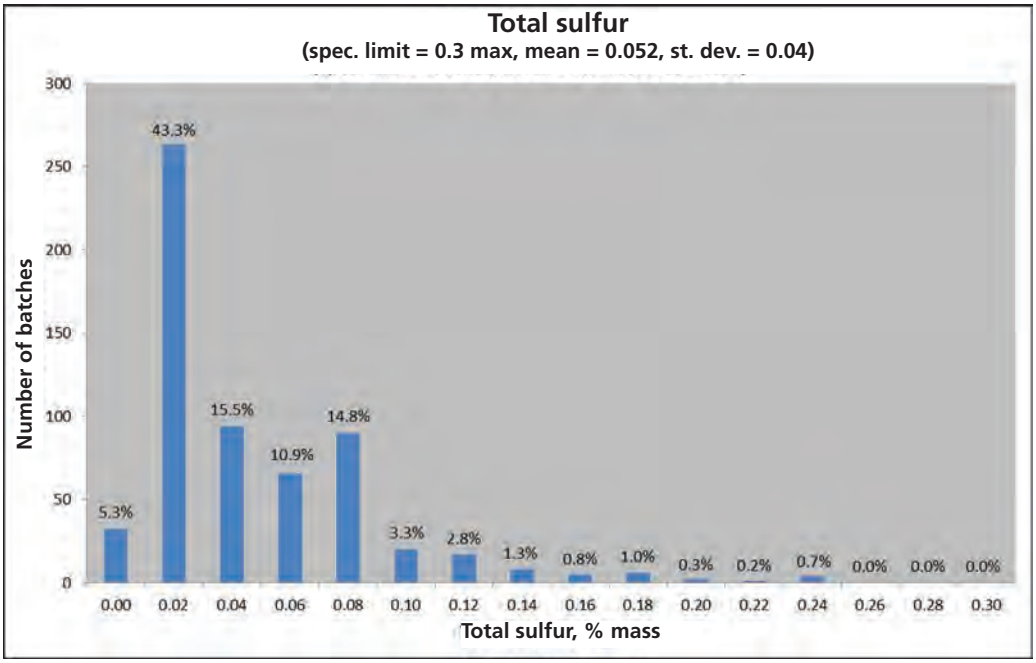

Figure 13: Total sulfur histogram 2009

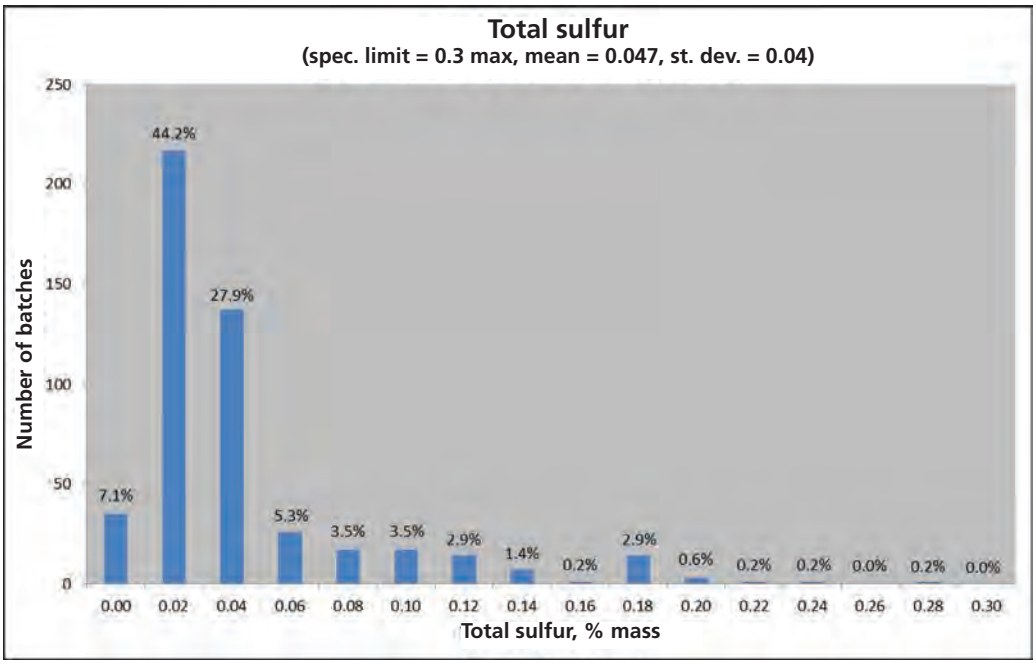

Figure 14: Total sulfur histogram 2010

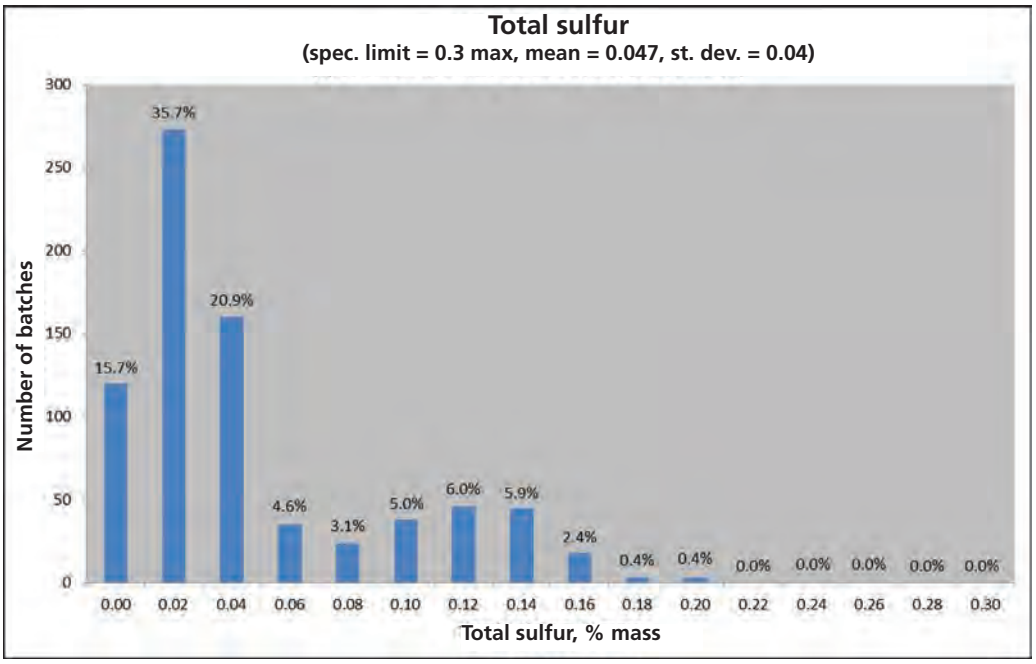

Figure 15: Total sulfur histogram 2011

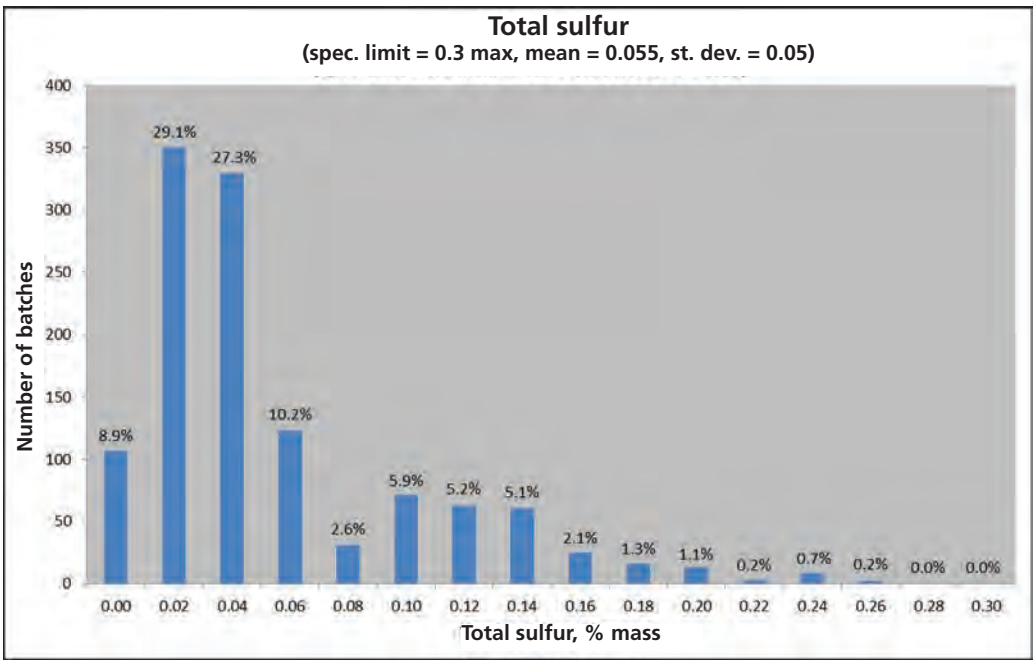

Figure 16: Total sulfur histogram 2012

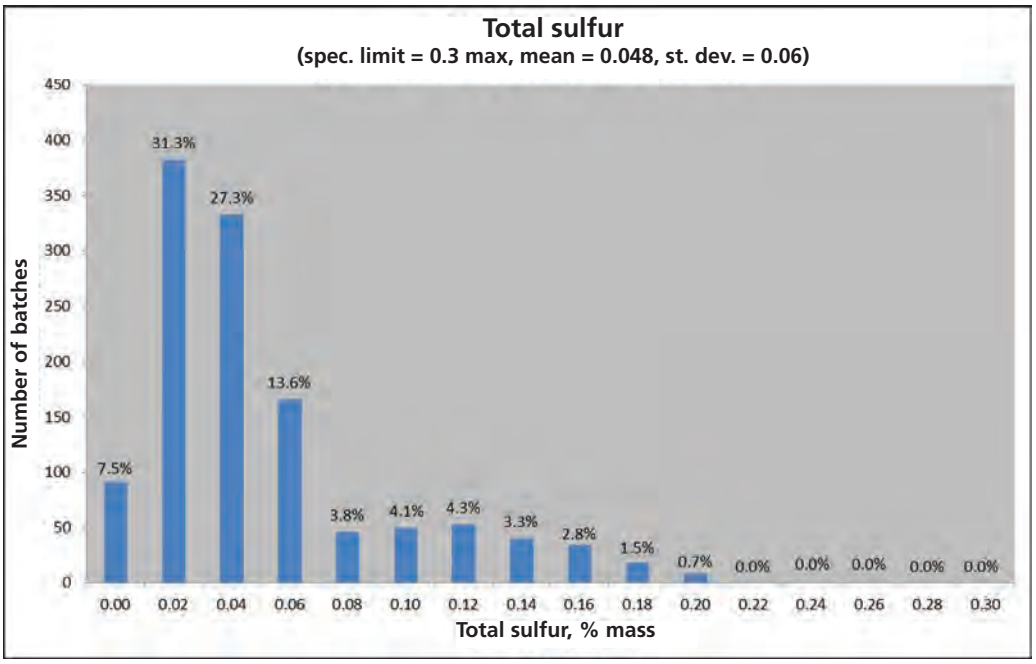

Figure 17: Total sulfur histogram 2013

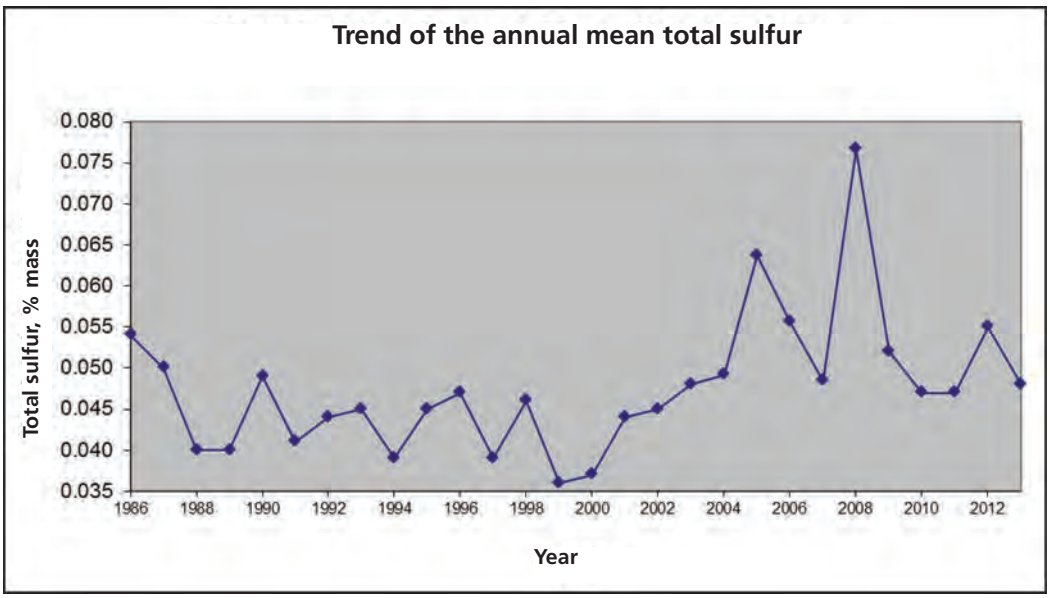

Figure 18: Total sulfur trend graph

B.4 MERCAPTAN SULFUR

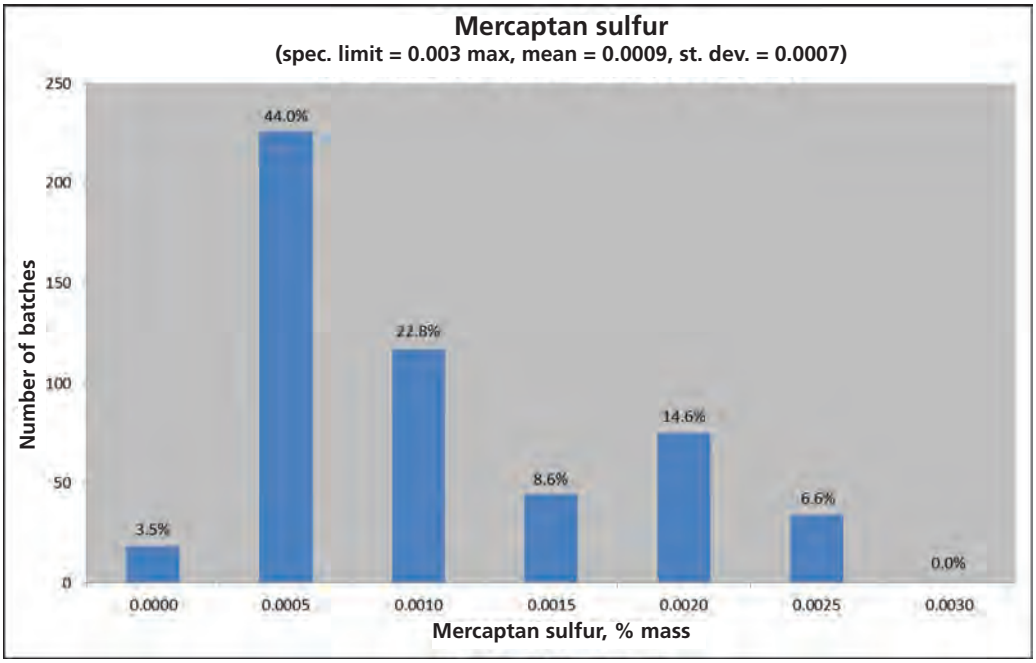

Figure 19: Mercaptan sulfur histogram 2009

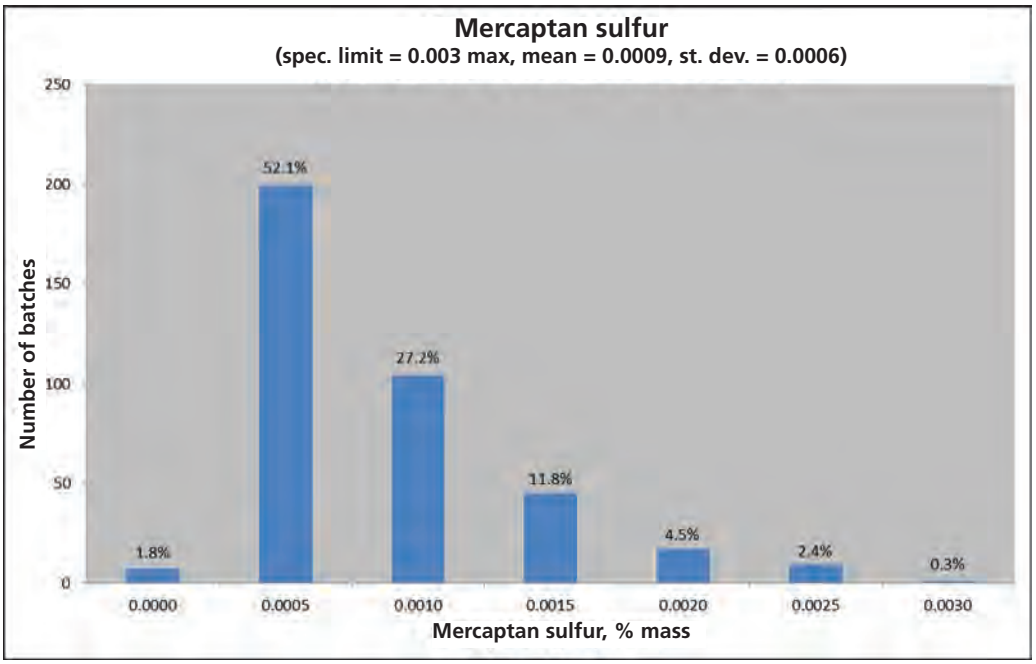

Figure 20: Mercaptan sulfur histogram 2010

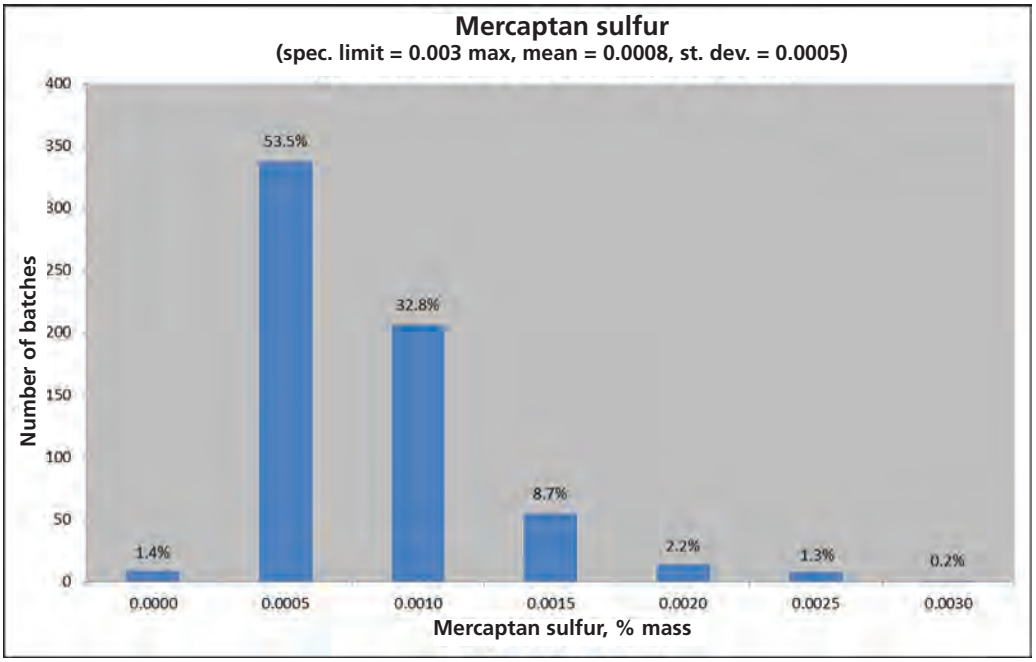

Figure 21: Mercaptan sulfur histogram 2011

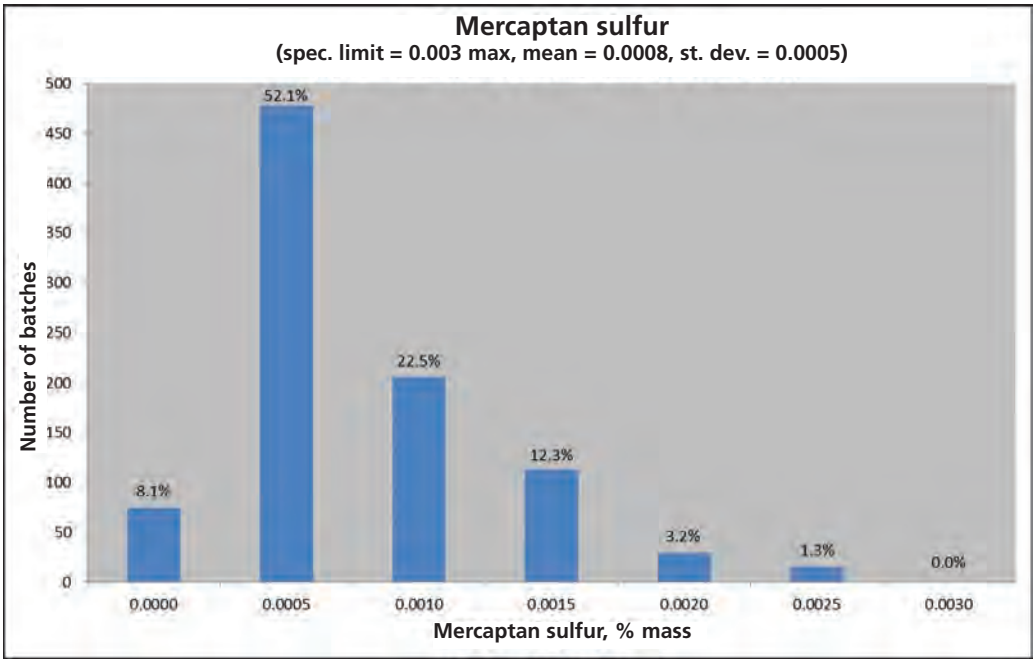

Figure 22: Mercaptan sulfur histogram 2012

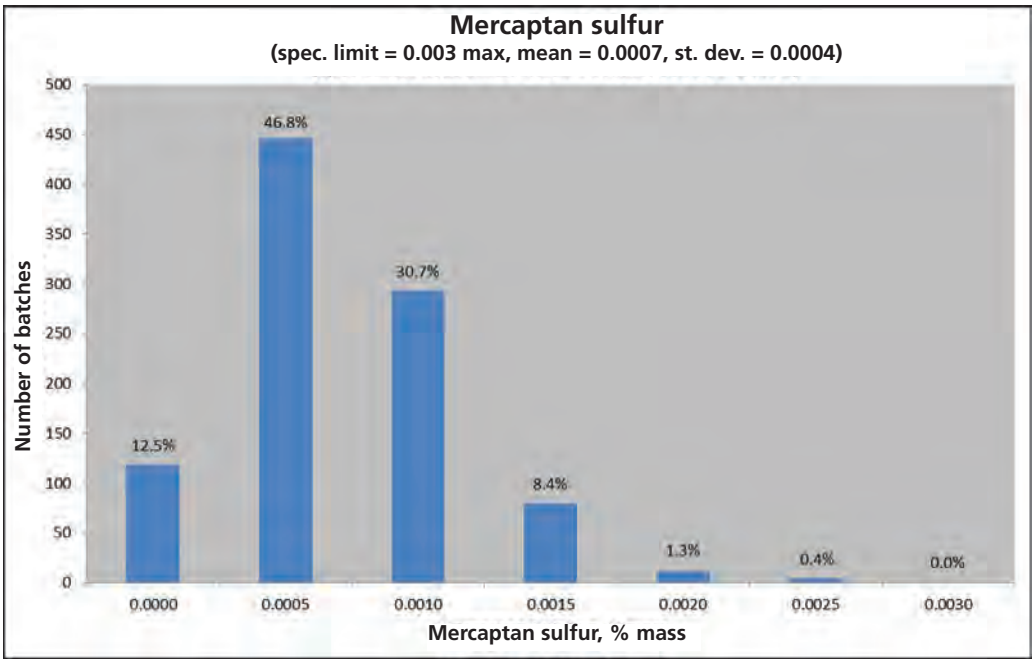

Figure 23: Mercaptan sulfur histogram 2013

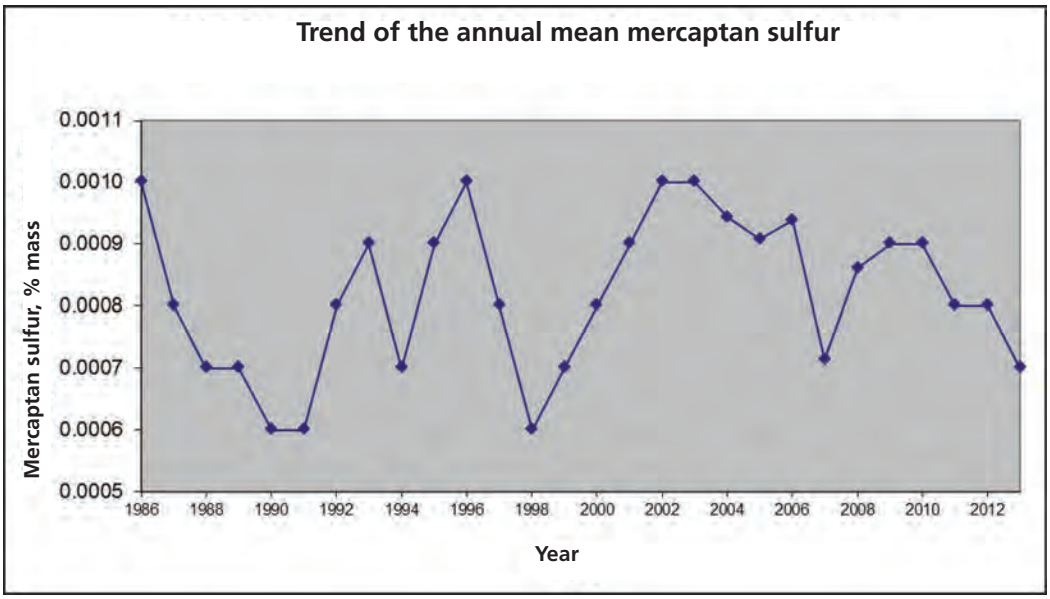

Figure 24: Mercaptan sulfur trend graph

B.5 DISTILLATION IBP

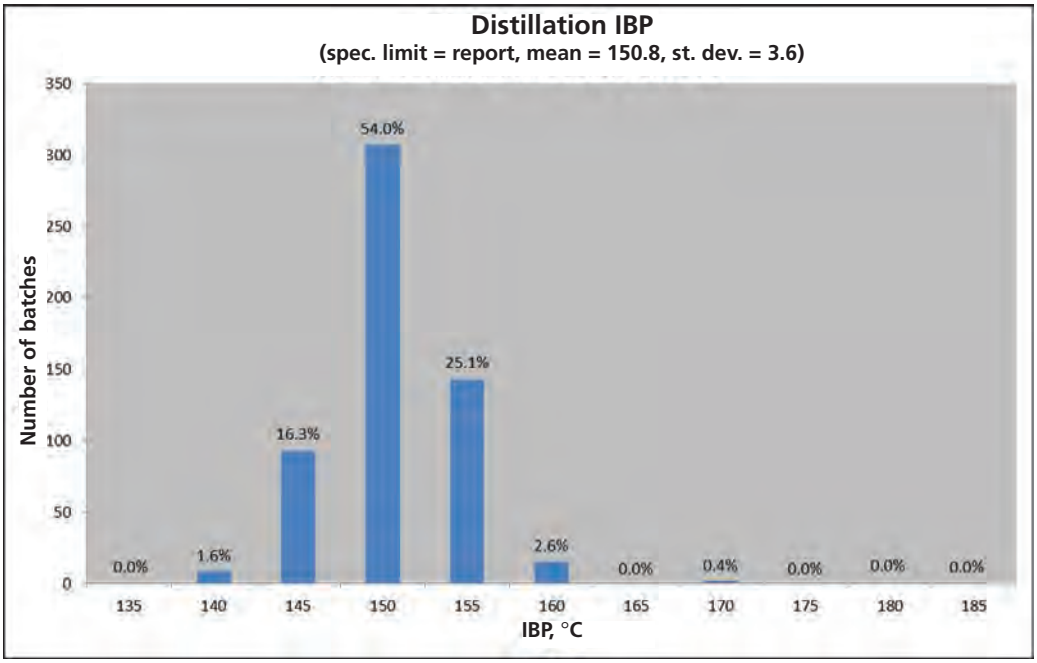

Figure 25: Distillation IBP histogram 2009

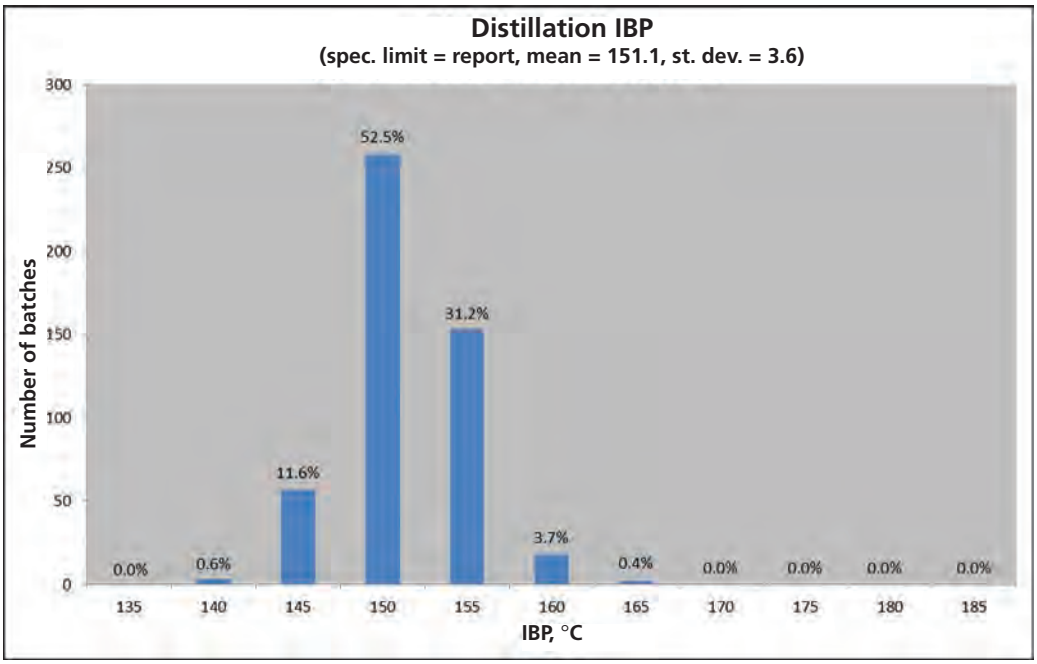

Figure 26: Distillation IBP histogram 2010

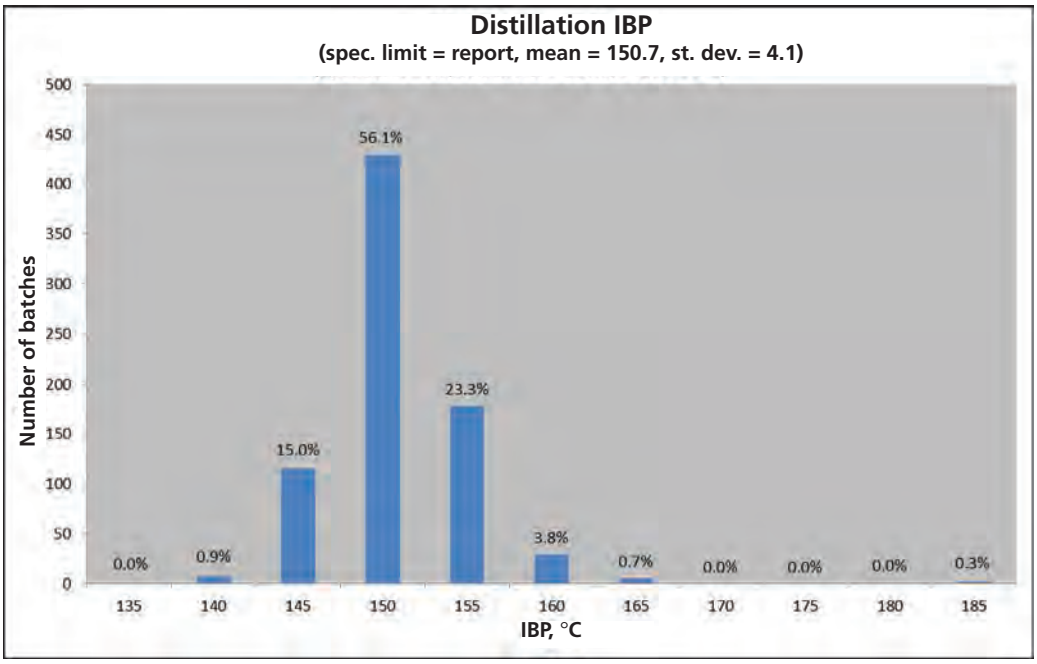

Figure 27: Distillation IBP histogram 2011

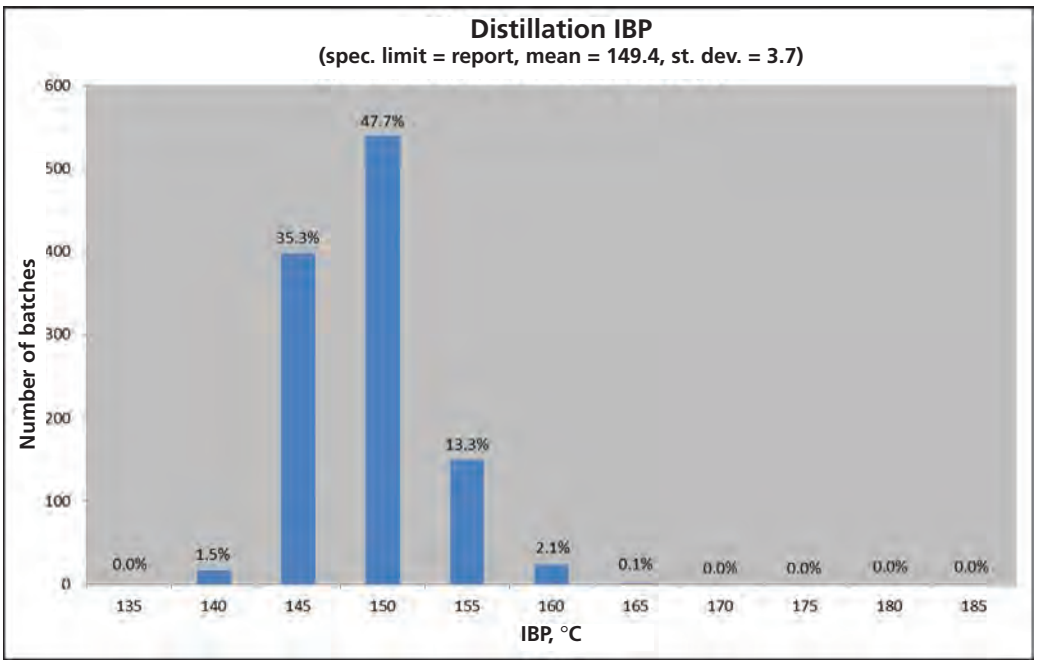

Figure 28: Distillation IBP histogram 2012

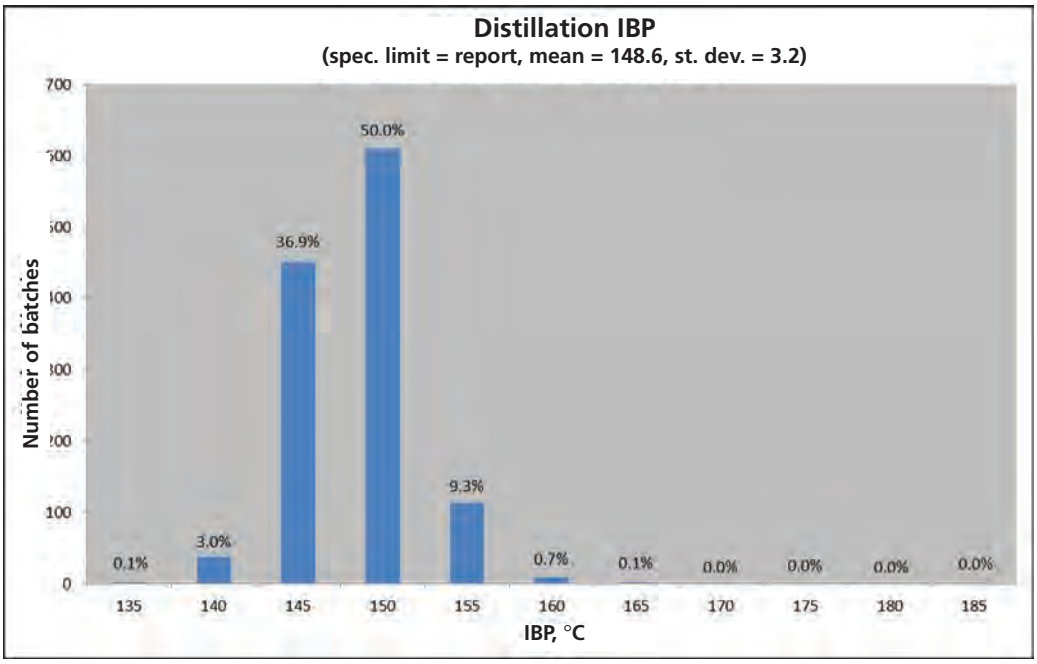

Figure 29: Distillation IBP histogram 2013

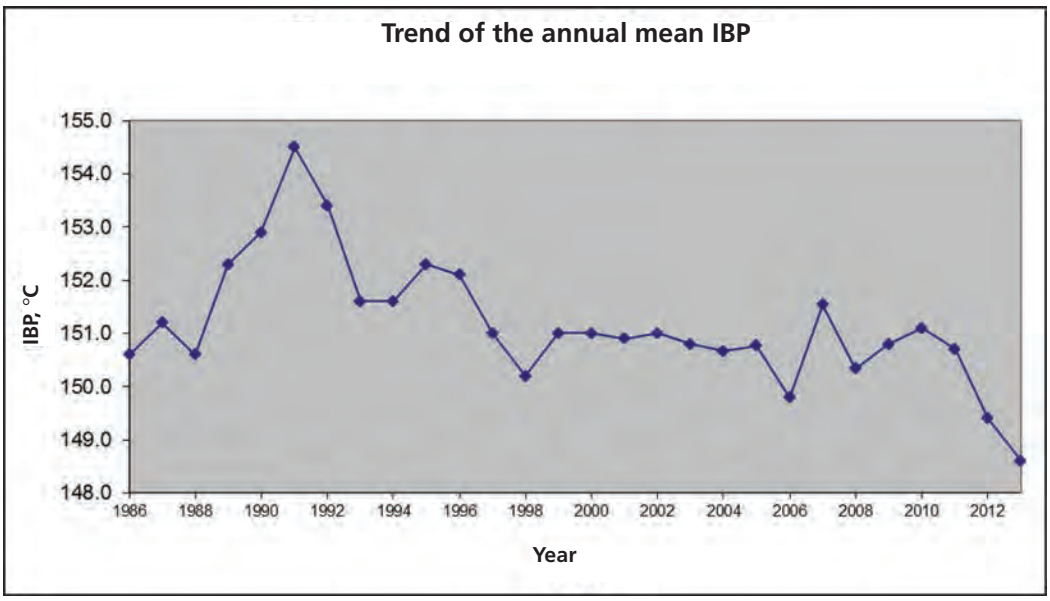

Figure 30: Distillation IBP trend graph

B.6 DISTILLATION 10 % RECOVERY

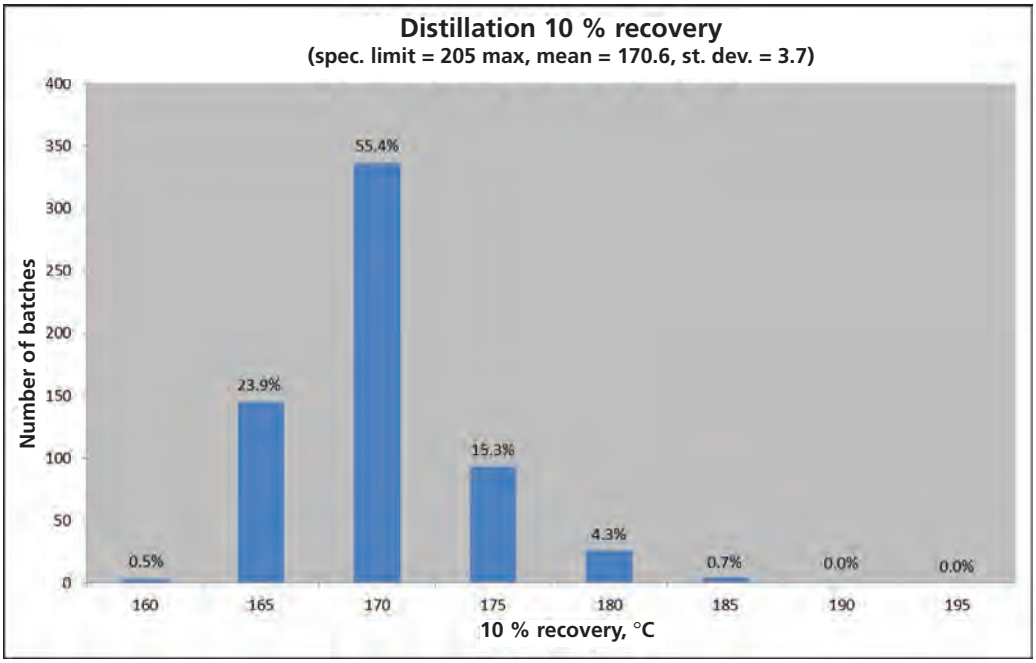

Figure 31: Distillation 10 % recovery histogram 2009

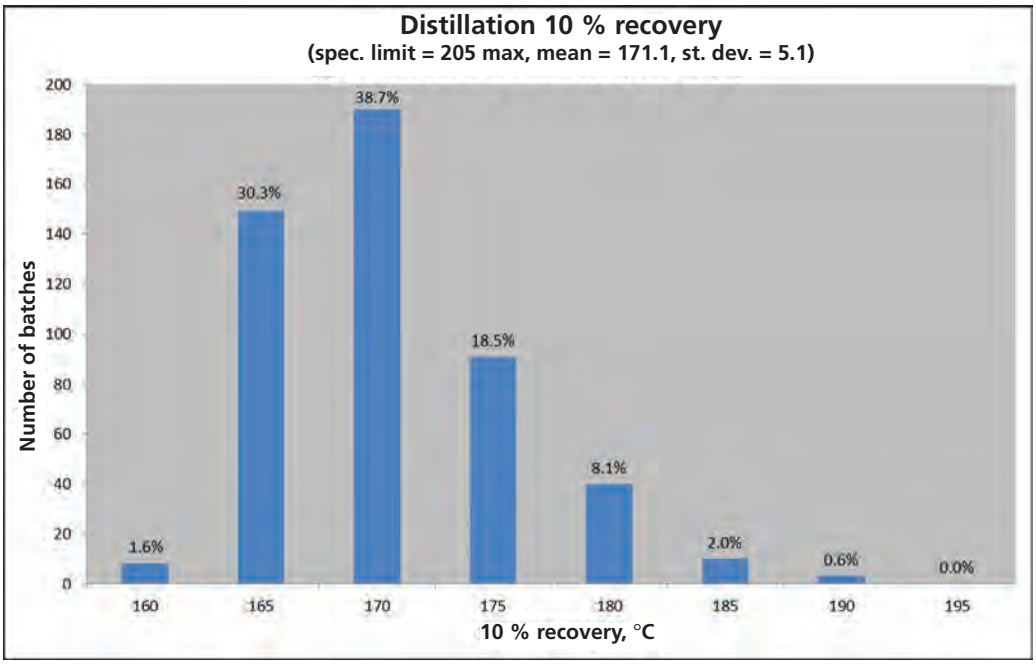

Figure 32: Distillation 10 % recovery histogram 2010

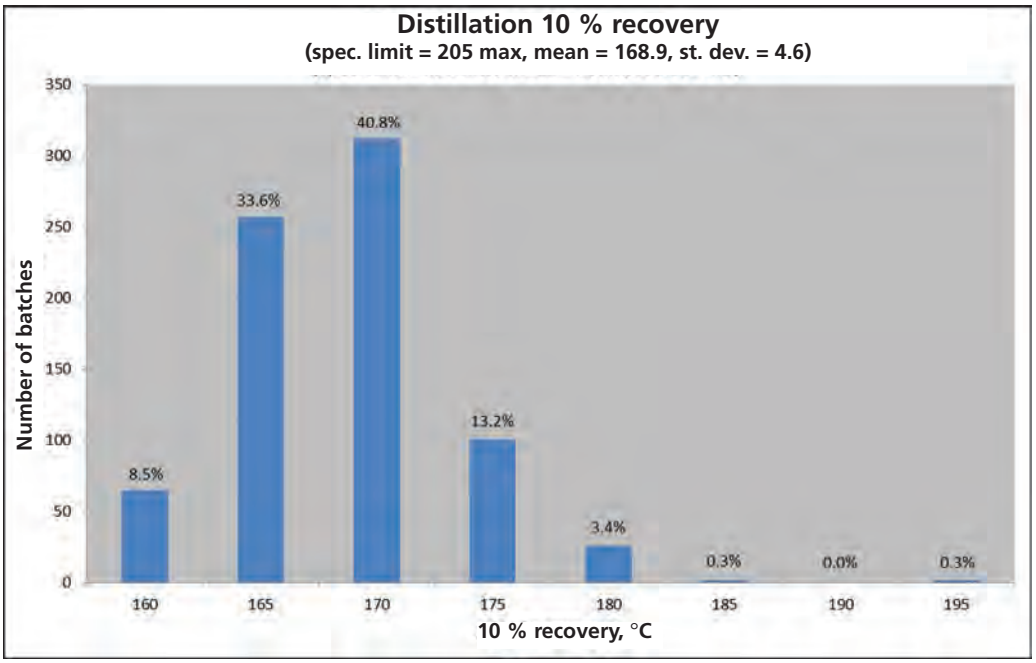

Figure 33: Distillation 10 % recovery histogram 2011

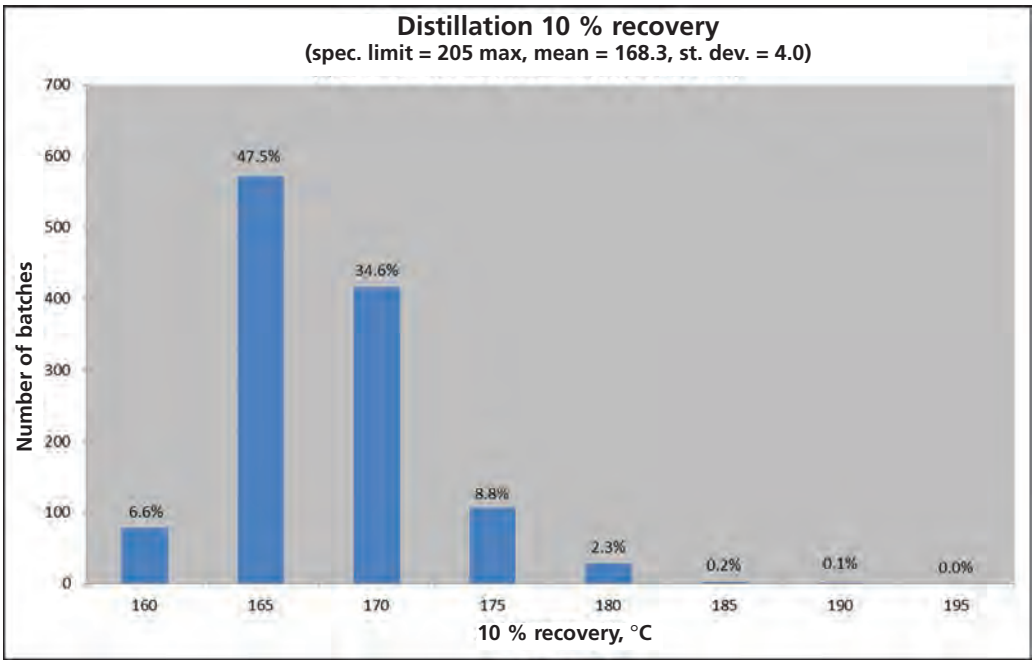

Figure 34: Distillation 10 % recovery histogram 2012

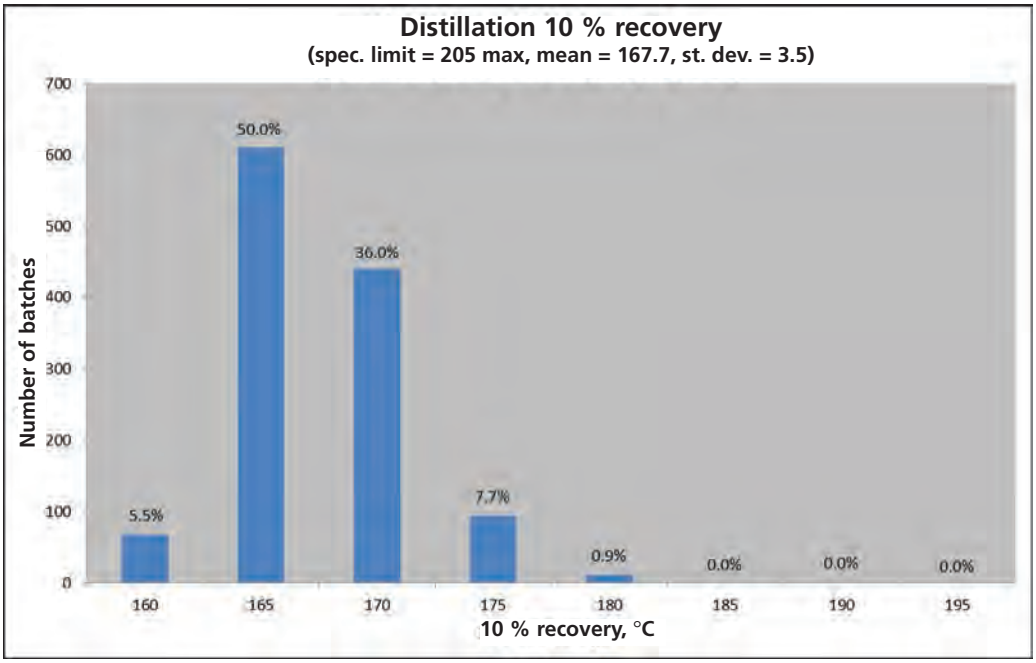

Figure 35: Distillation 10 % recovery histogram 2013

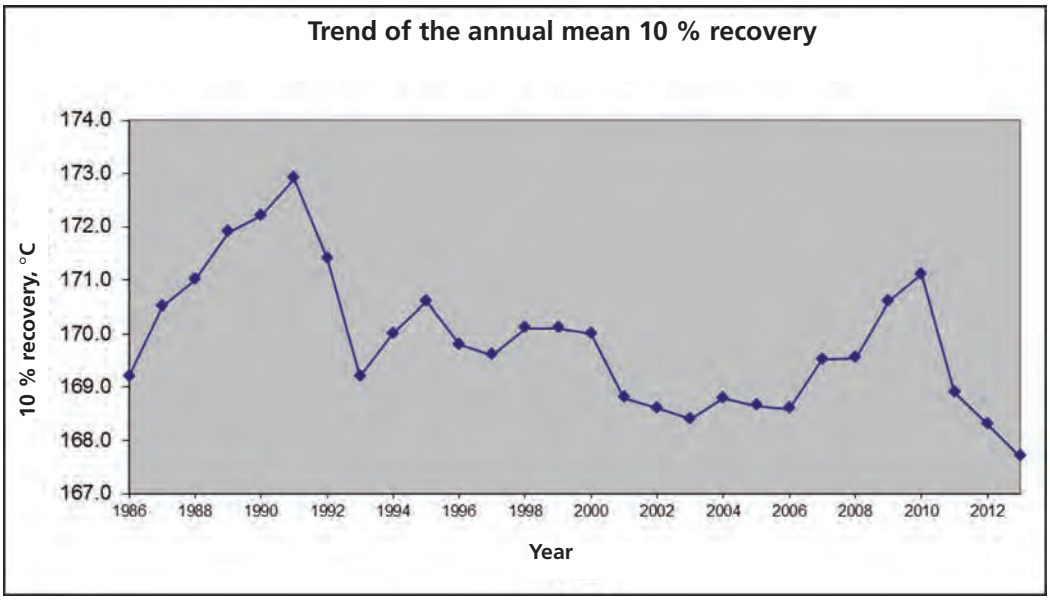

Figure 36: Distillation 10 % recovery trend graph

B.7 DISTILLATION 50 % RECOVERY

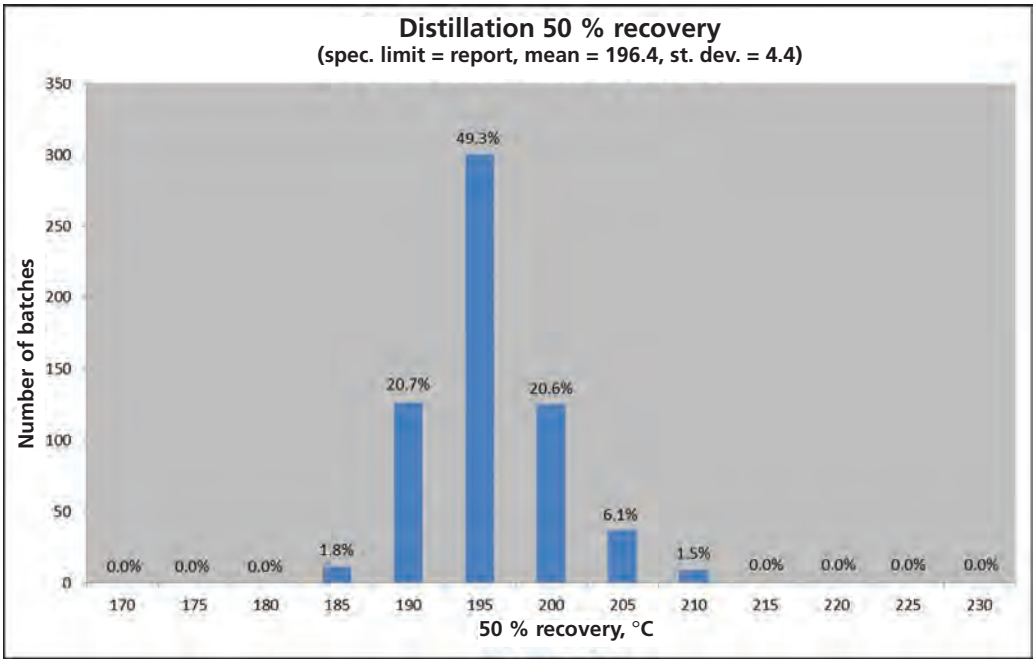

Figure 37: Distillation 50 % recovery histogram 2009

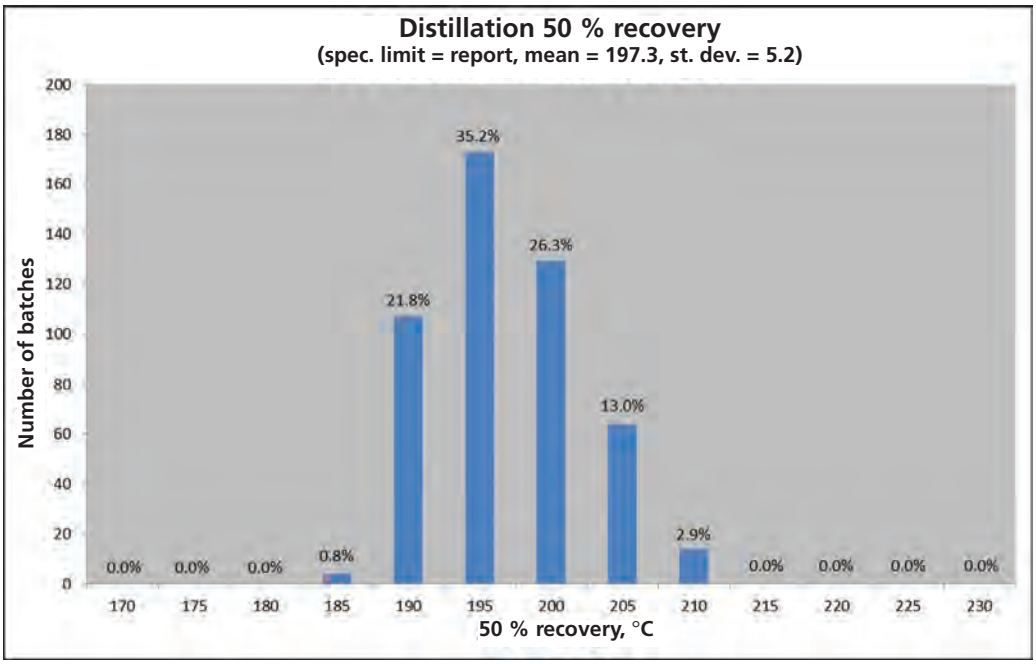

Figure 38: Distillation 50 % recovery histogram 2010

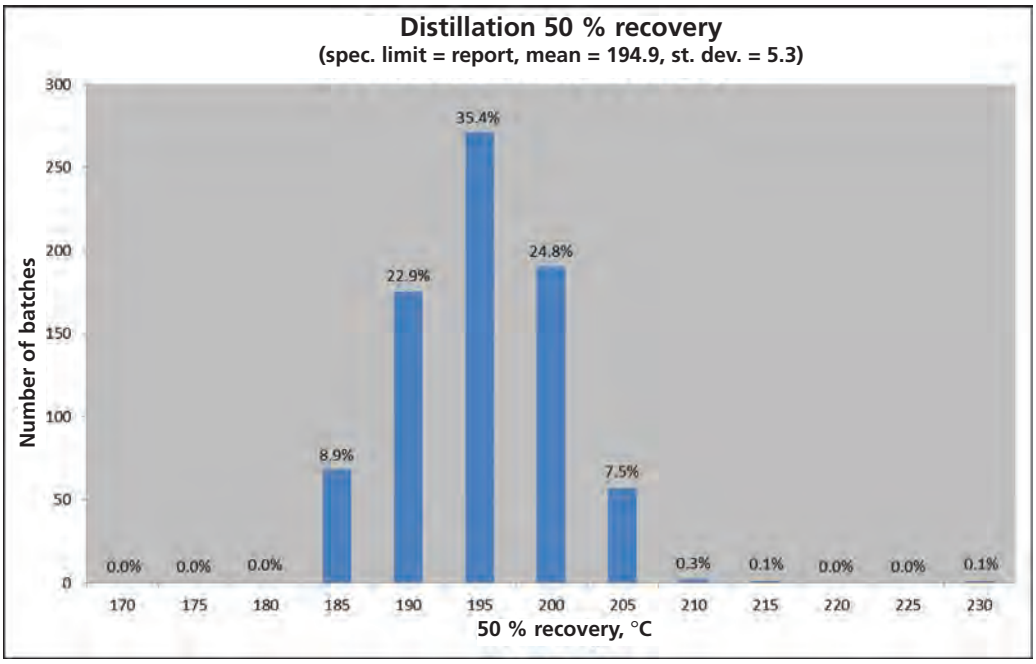

Figure 39: Distillation 50 % recovery histogram 2011

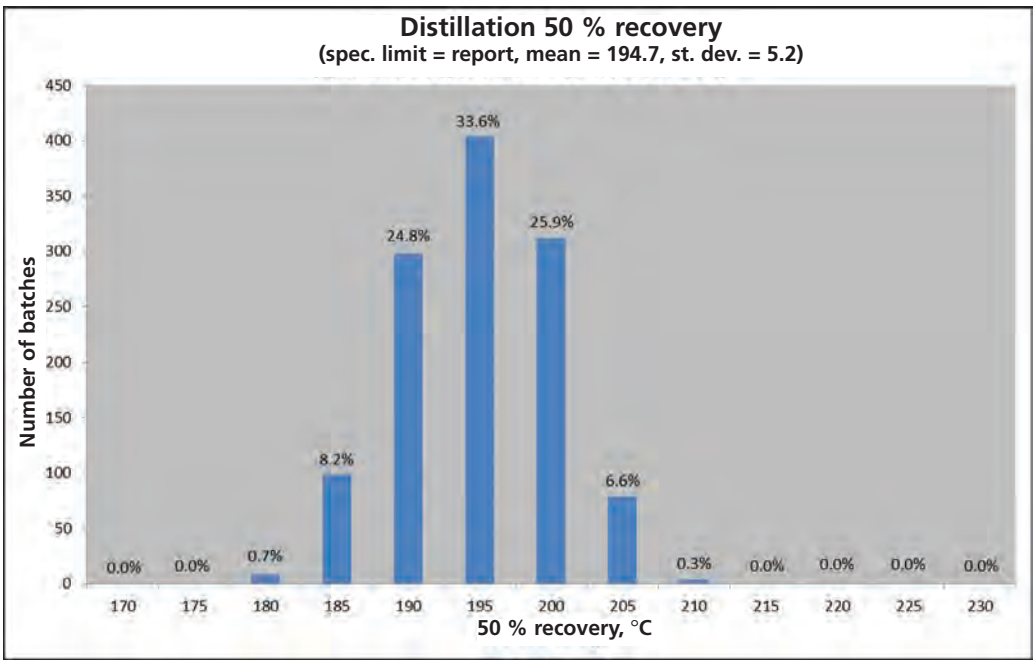

Figure 40: Distillation 50 % recovery histogram 2012

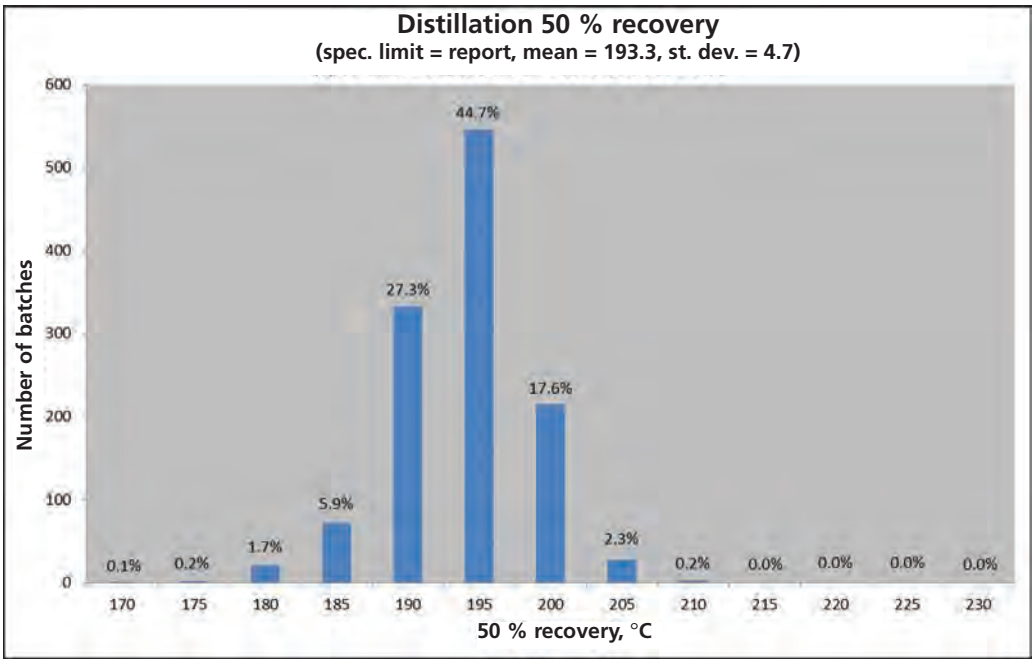

Figure 41: Distillation 50 % recovery histogram 2013

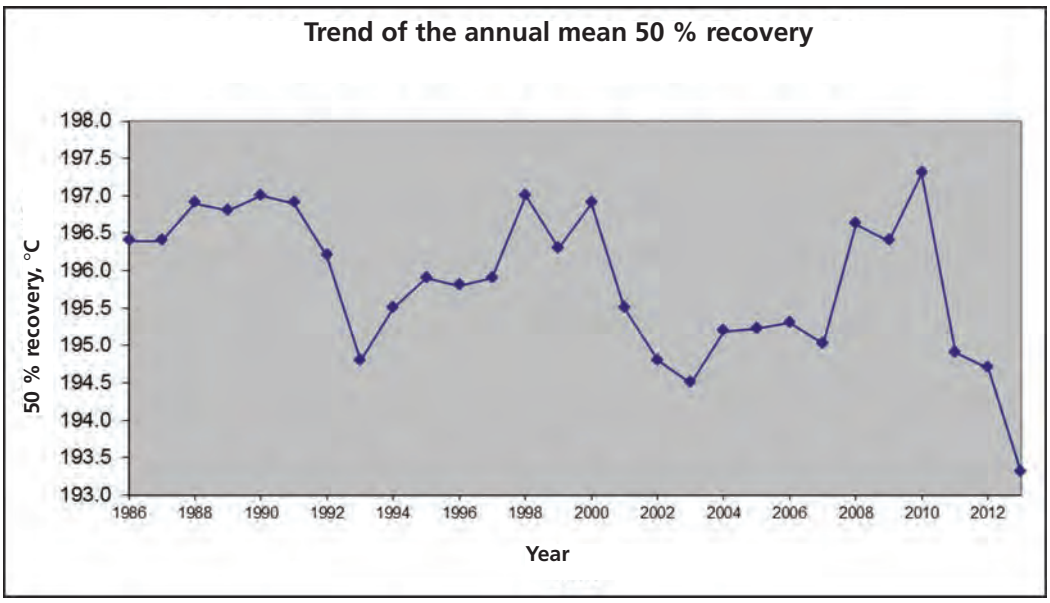

Figure 42: Distillation 50 % recovery trend graph

B.8 DISTILLATION 90 % RECOVERY

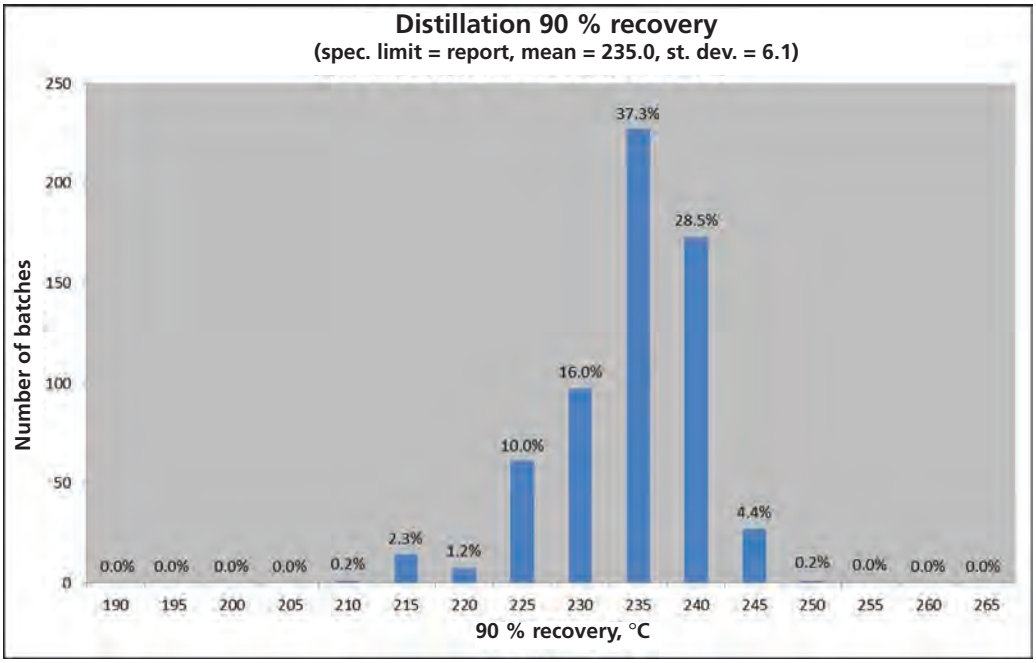

Figure 43: Distillation 90 % recovery histogram 2009

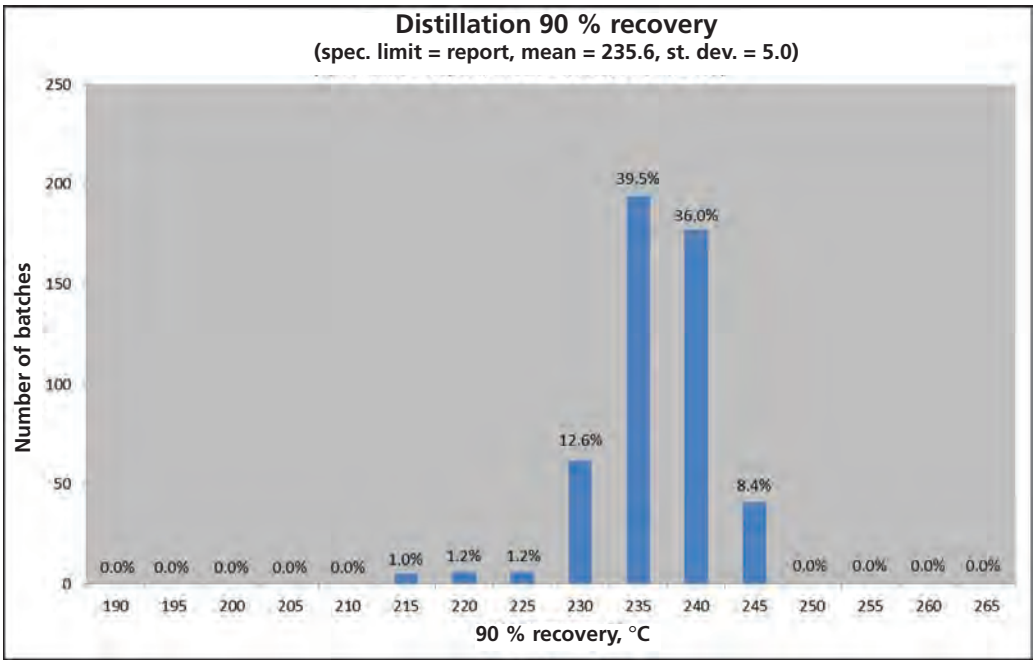

Figure 44: Distillation 90 % recovery histogram 2010

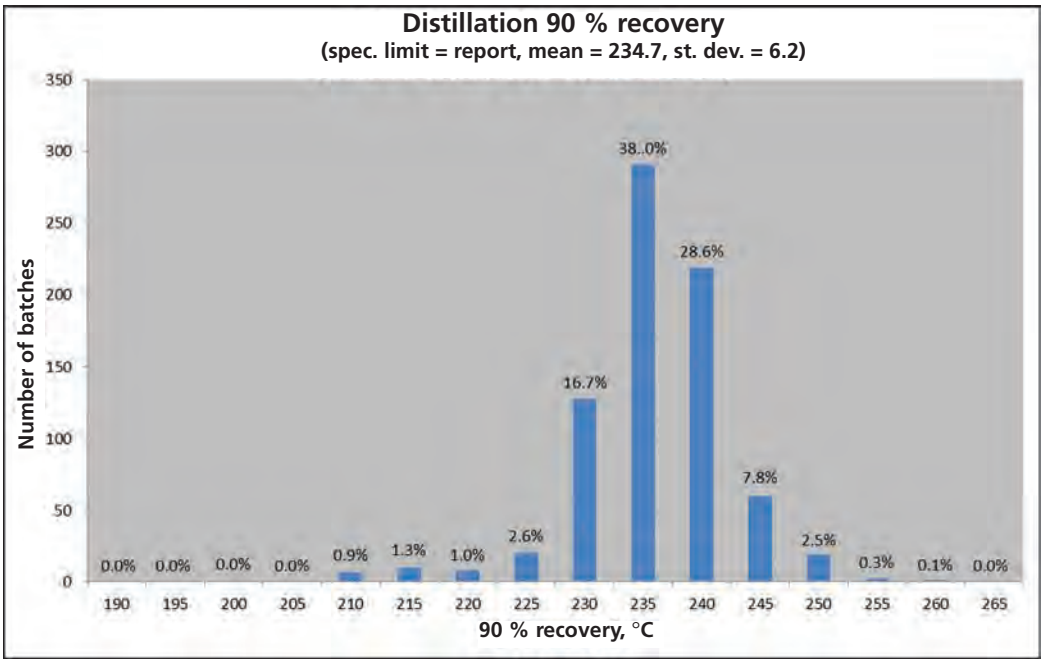

Figure 45: Distillation 90 % recovery histogram 2011

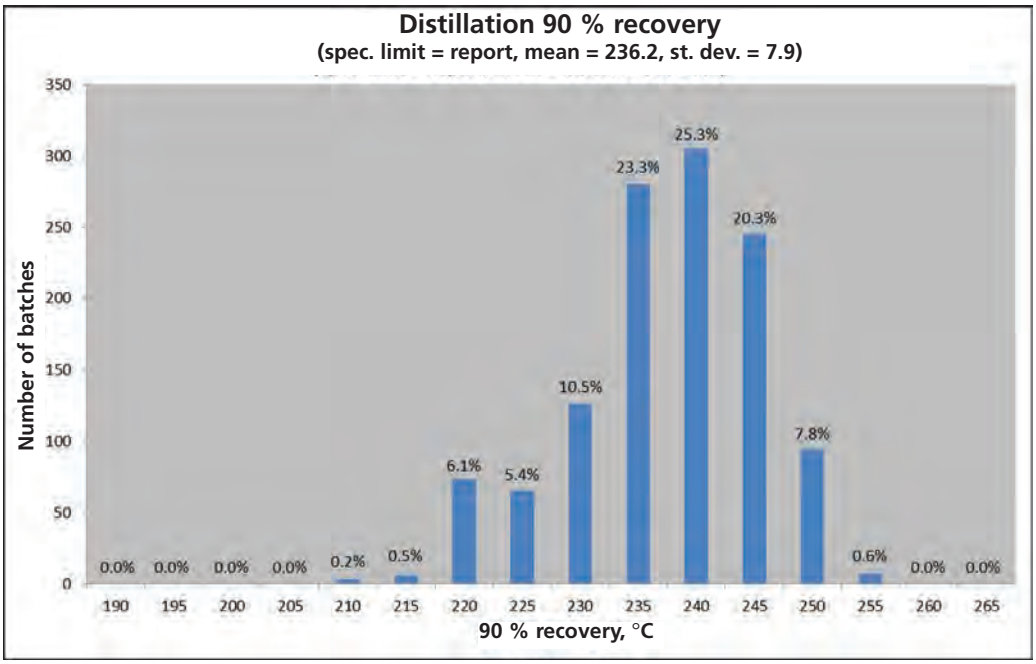

Figure 46: Distillation 90 % recovery histogram 2012

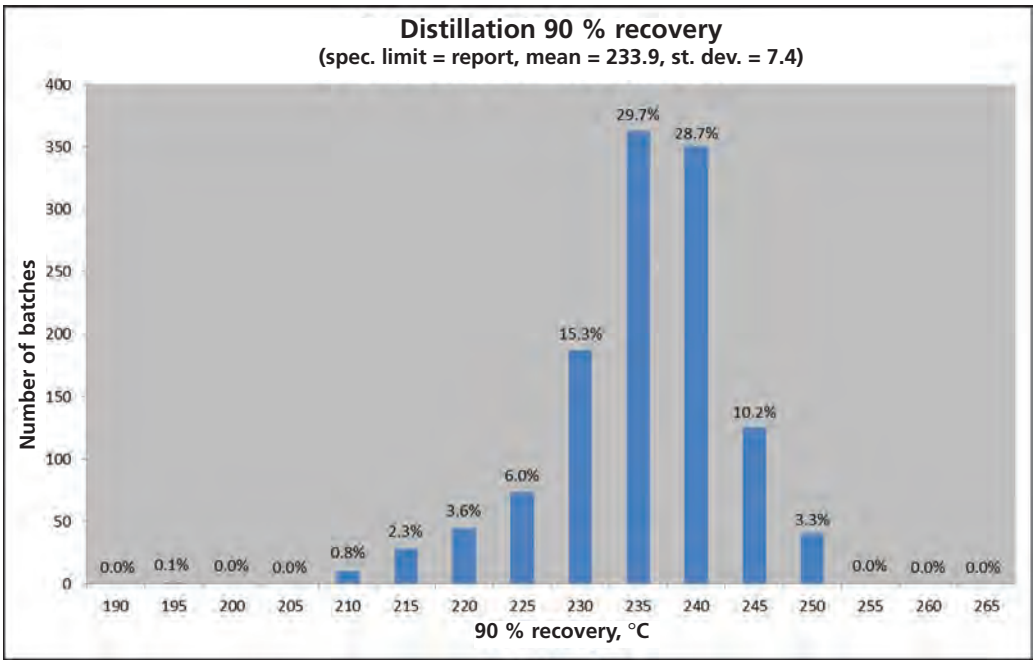

Figure 47: Distillation 90 % recovery histogram 2013

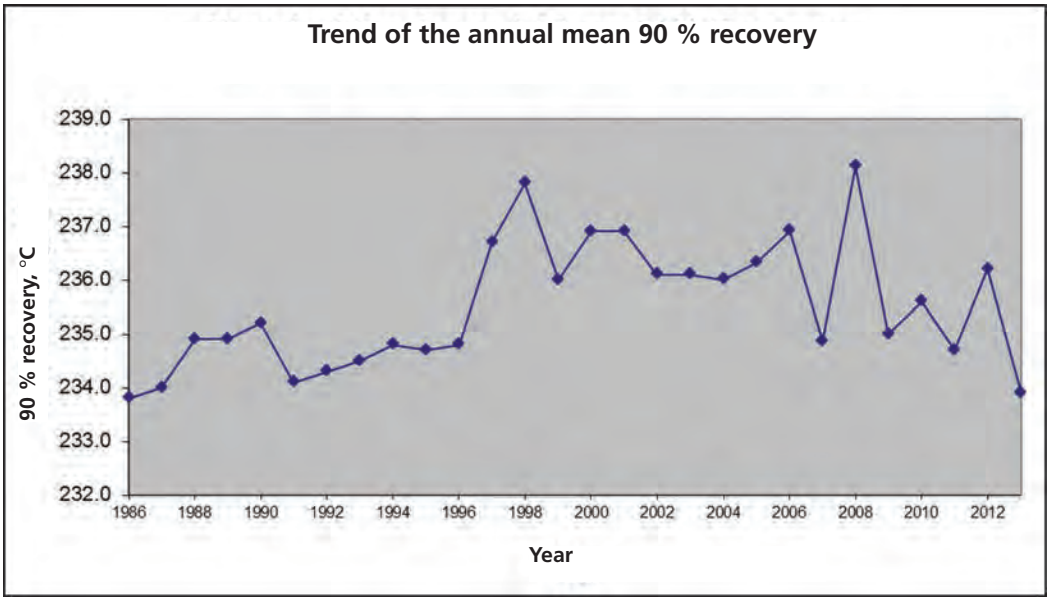

Figure 48: Distillation 90 % recovery trend graph

B.9 DISTILLATION FBP

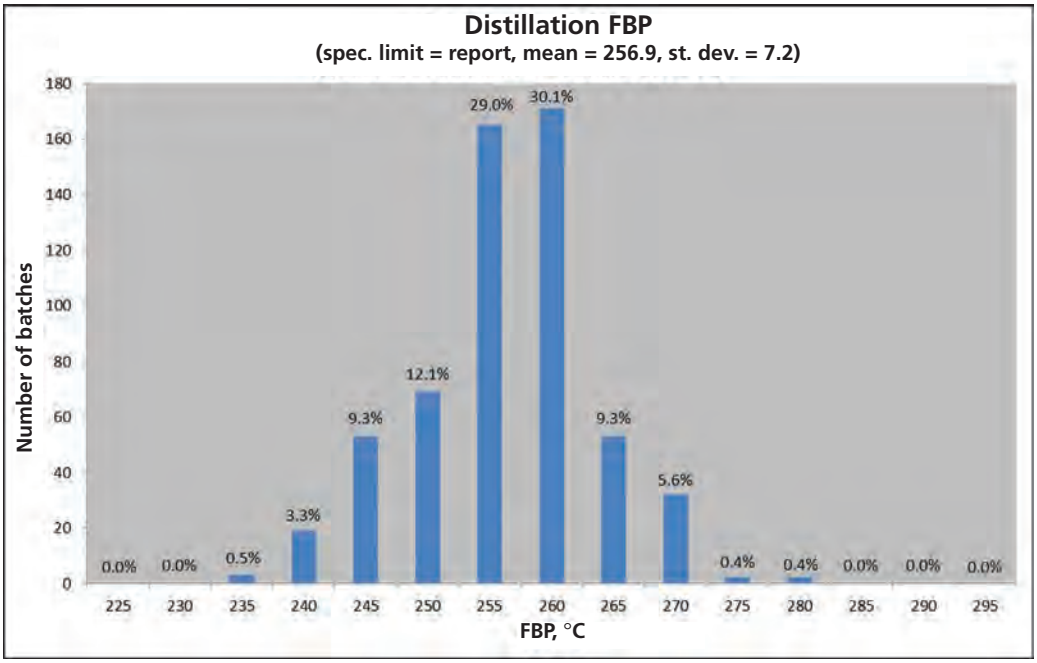

Figure 49: Distillation FBP histogram 2009

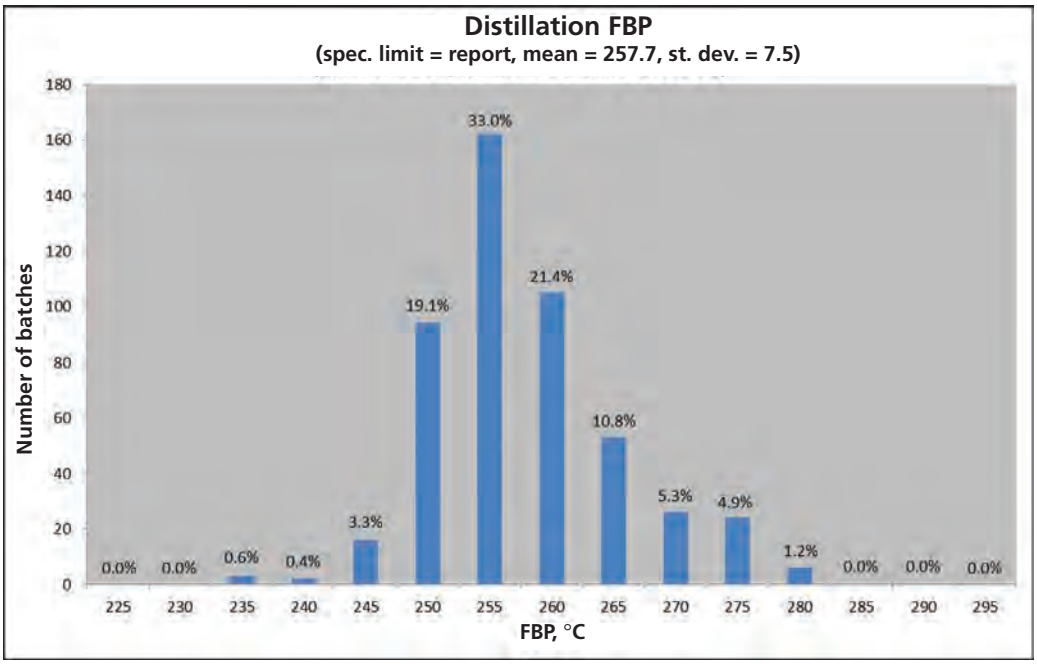

Figure 50: Distillation FBP histogram 2010

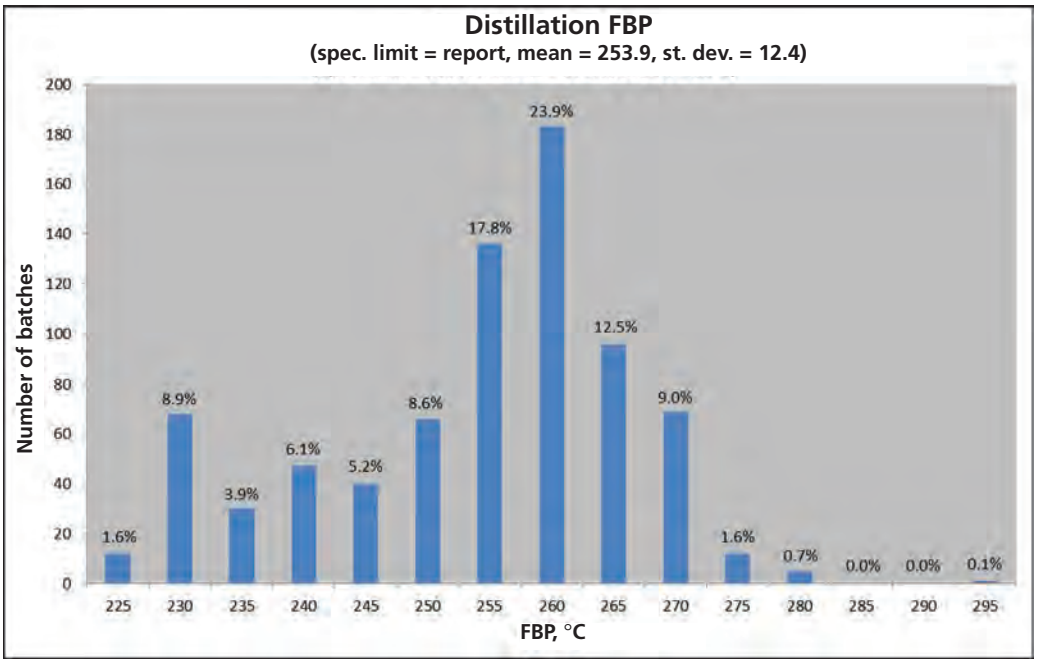

Figure 51: Distillation FBP histogram 2011

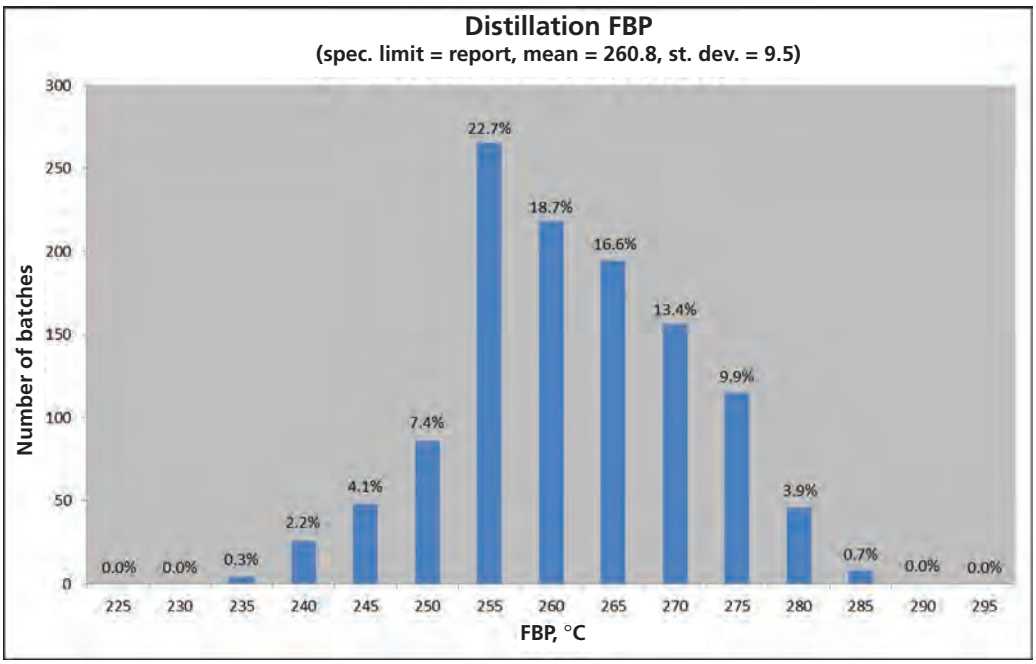

Figure 52: Distillation FBP histogram 2012

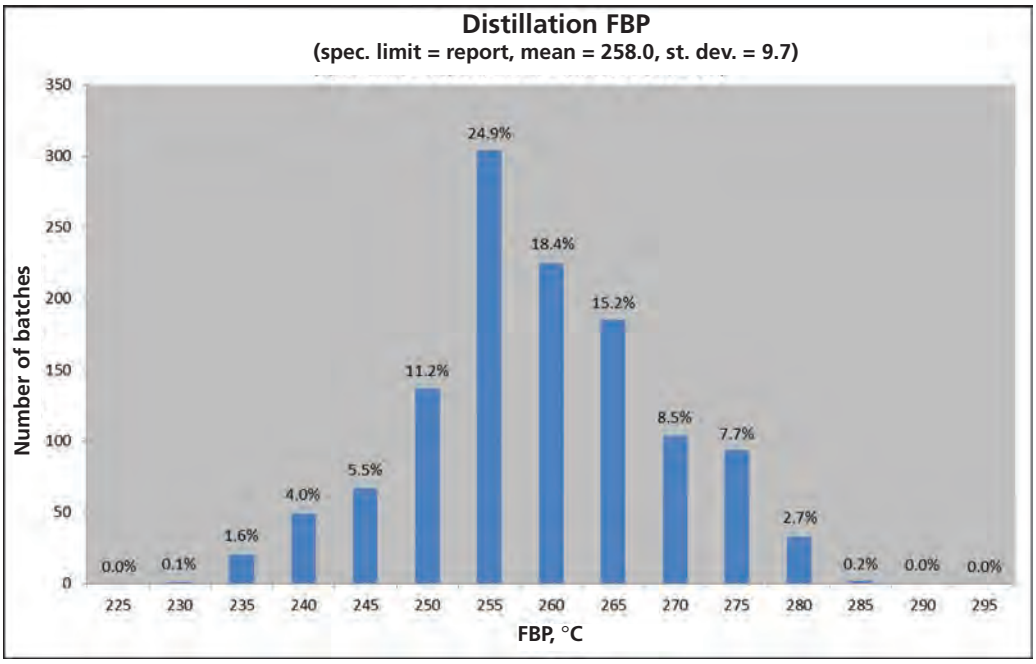

Figure 53: Distillation FBP histogram 2013

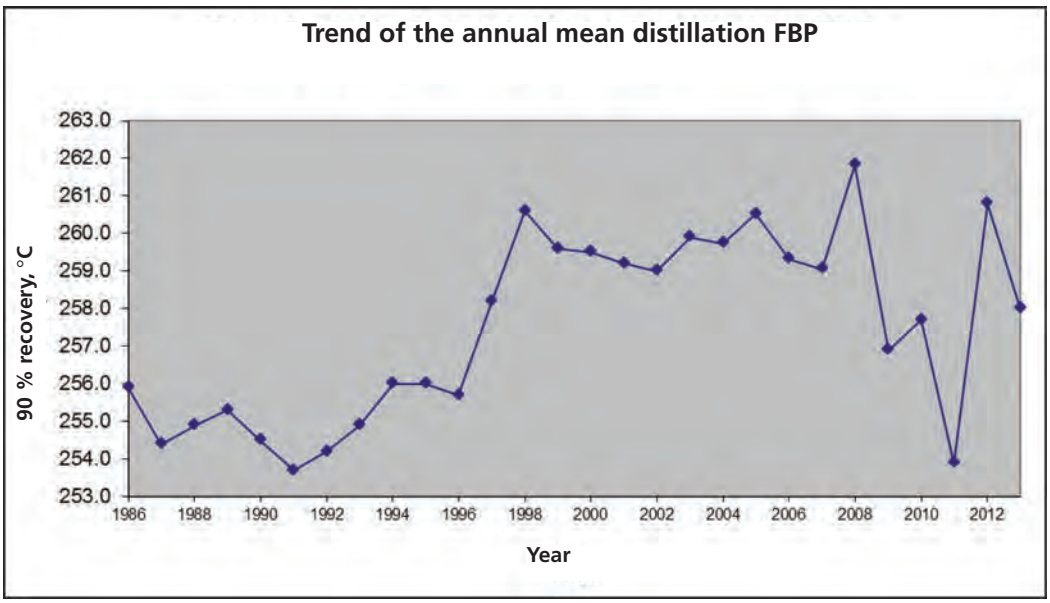

Figure 54: Distillation FBP trend graph

B.10 FLASH POINT

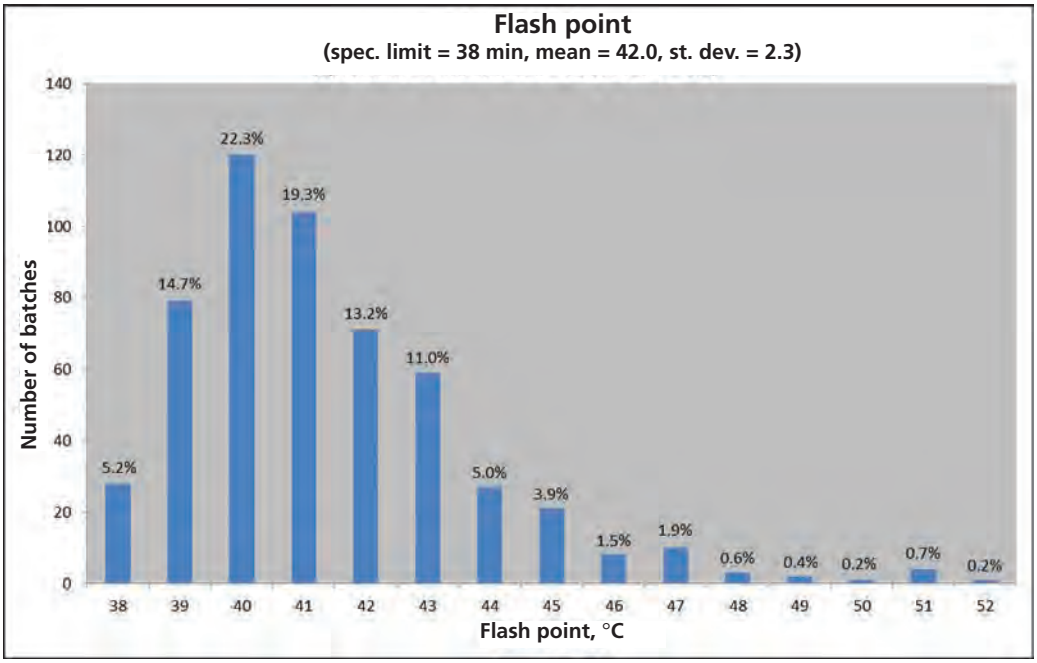

Figure 55: Flash point histogram 2009

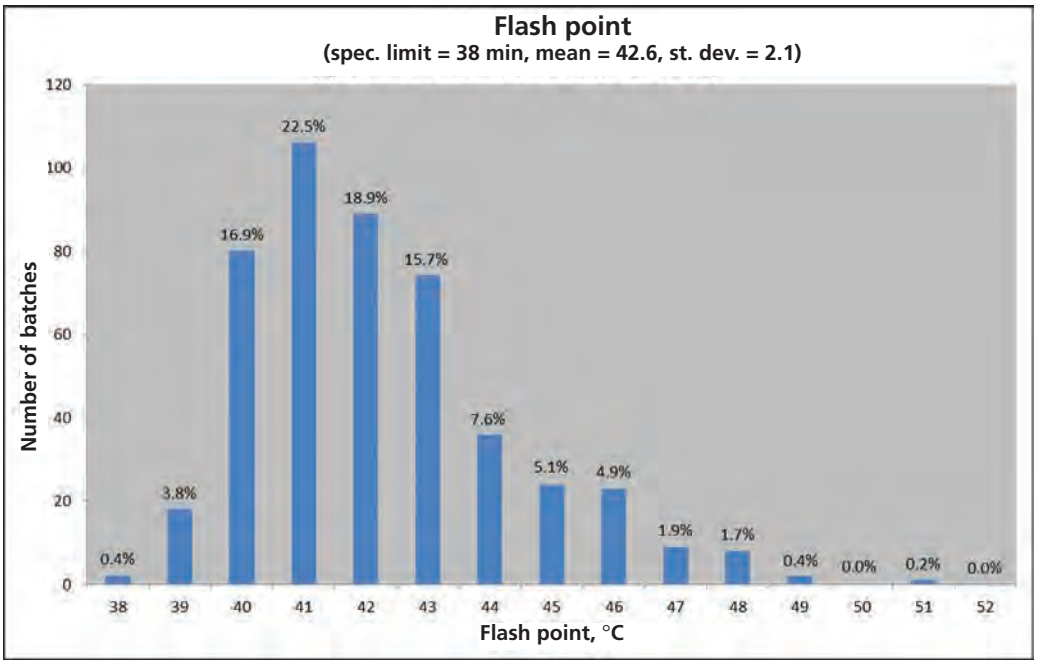

Figure 56: Flash point histogram 2010

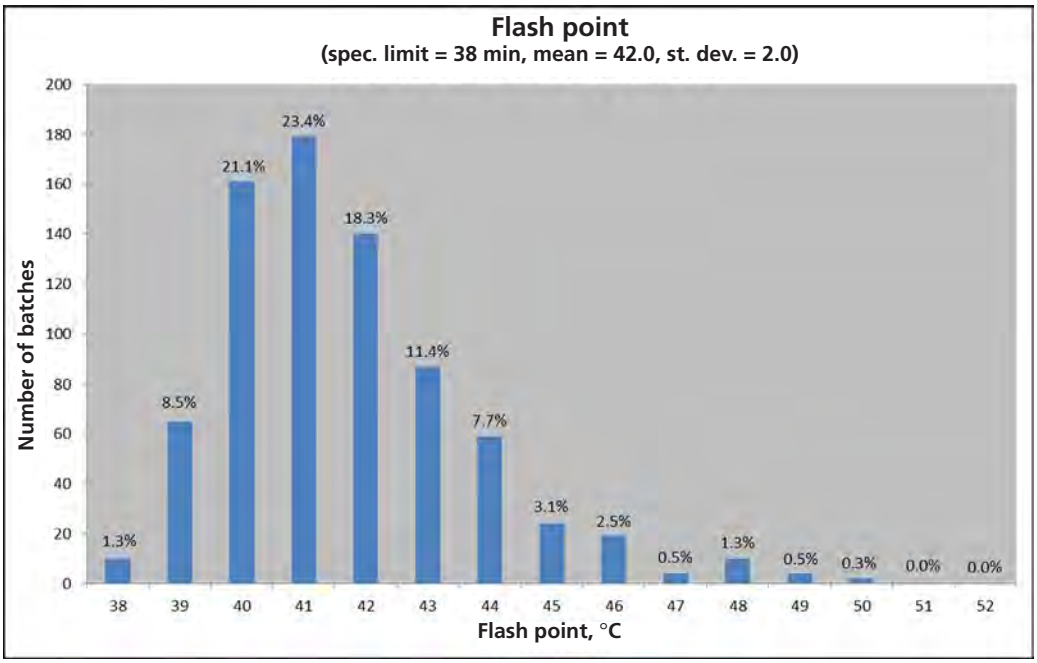

Figure 57: Flash point histogram 2011

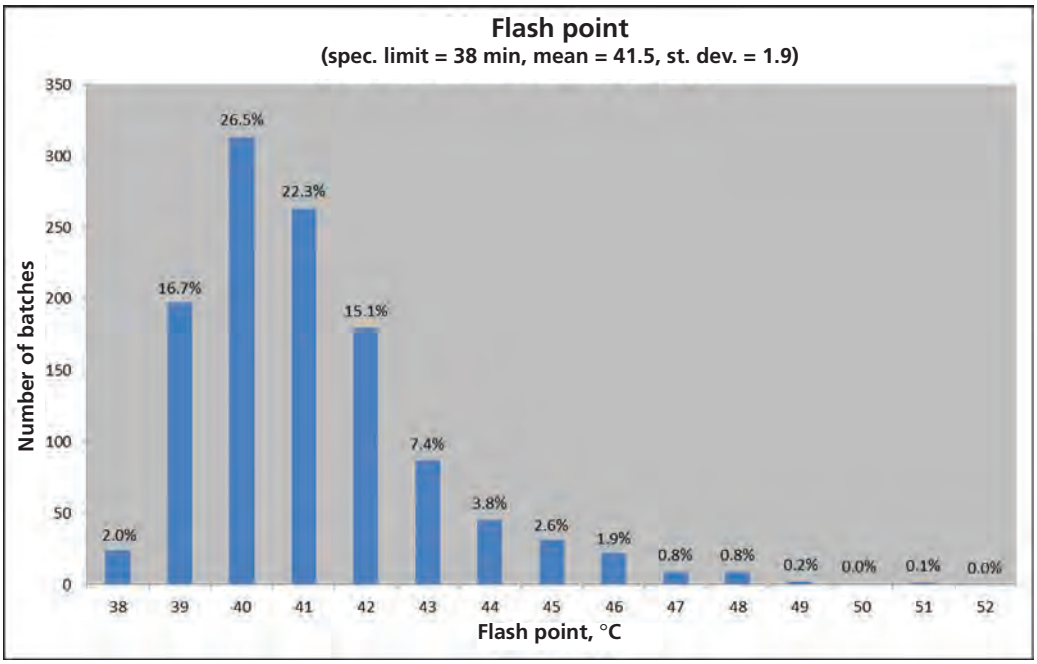

Figure 58: Flash point histogram 2012

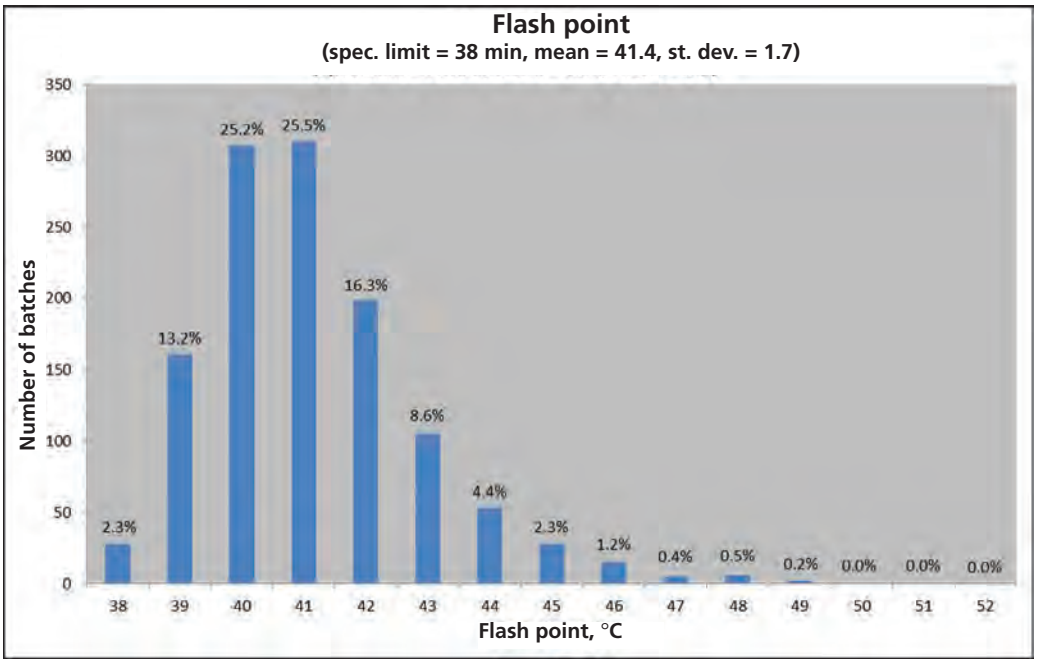

Figure 59: Flash point histogram 2013

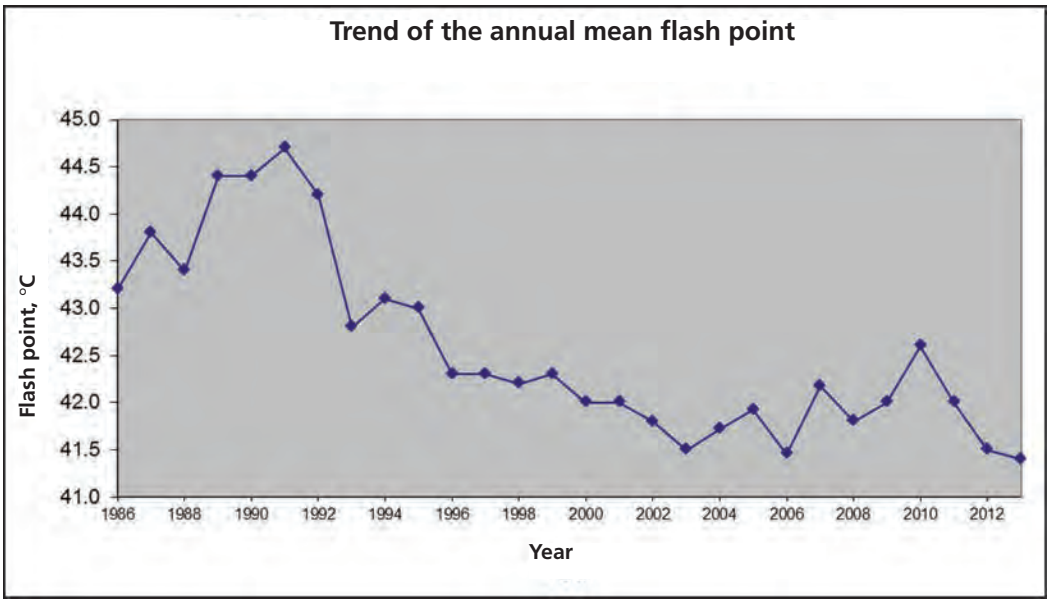

Figure 60: Flash point trend graph

B.11 DENSITY AT 15 °C

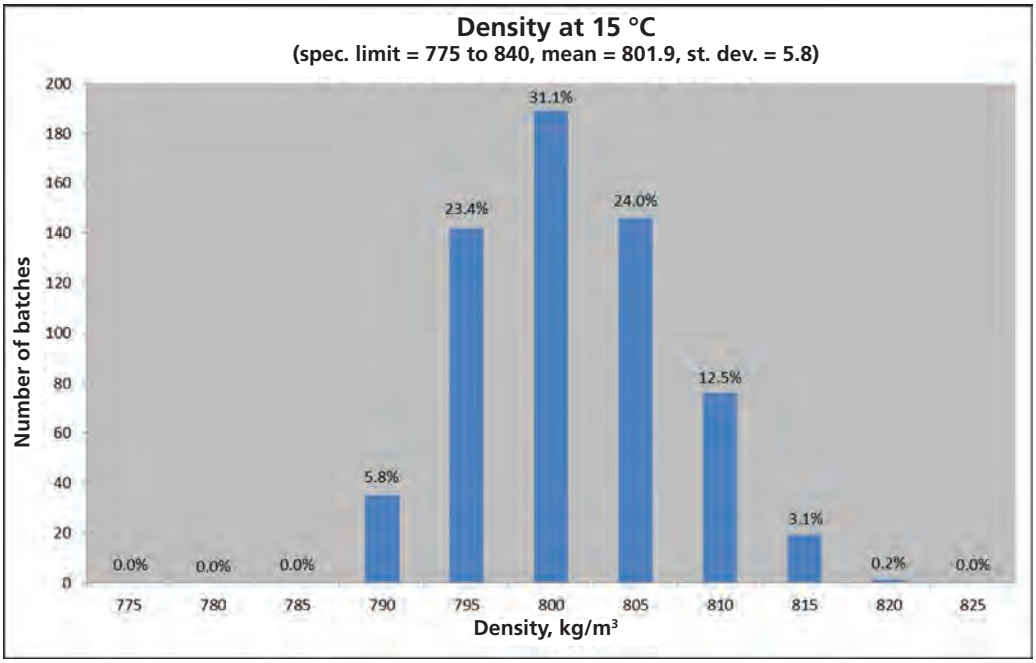

Figure 61: Density histogram 2009

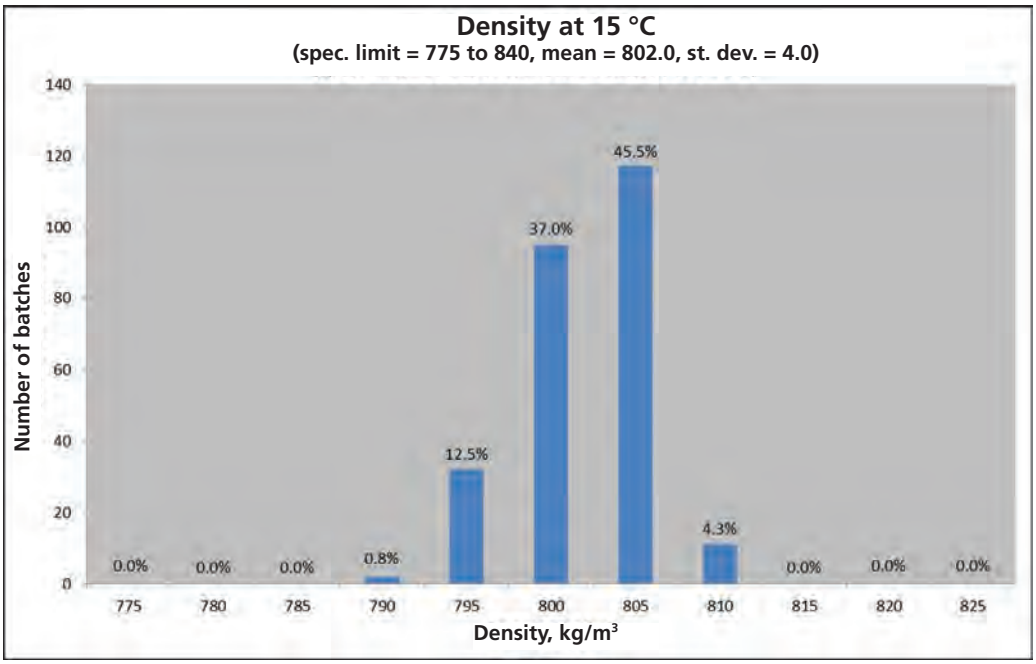

Figure 62: Density histogram 2010

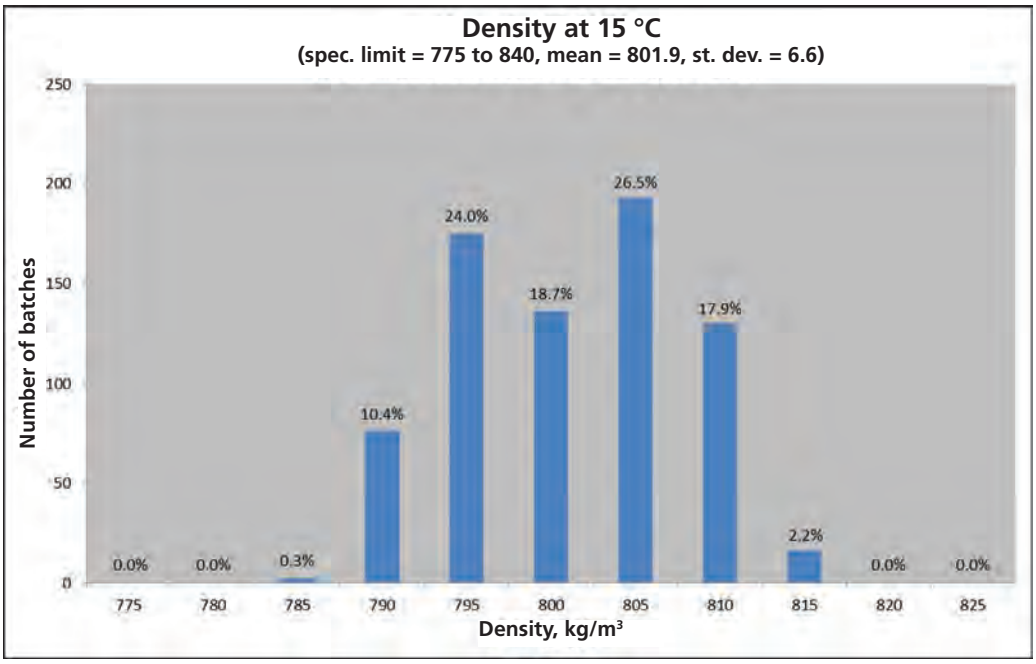

Figure 63: Density histogram 2011

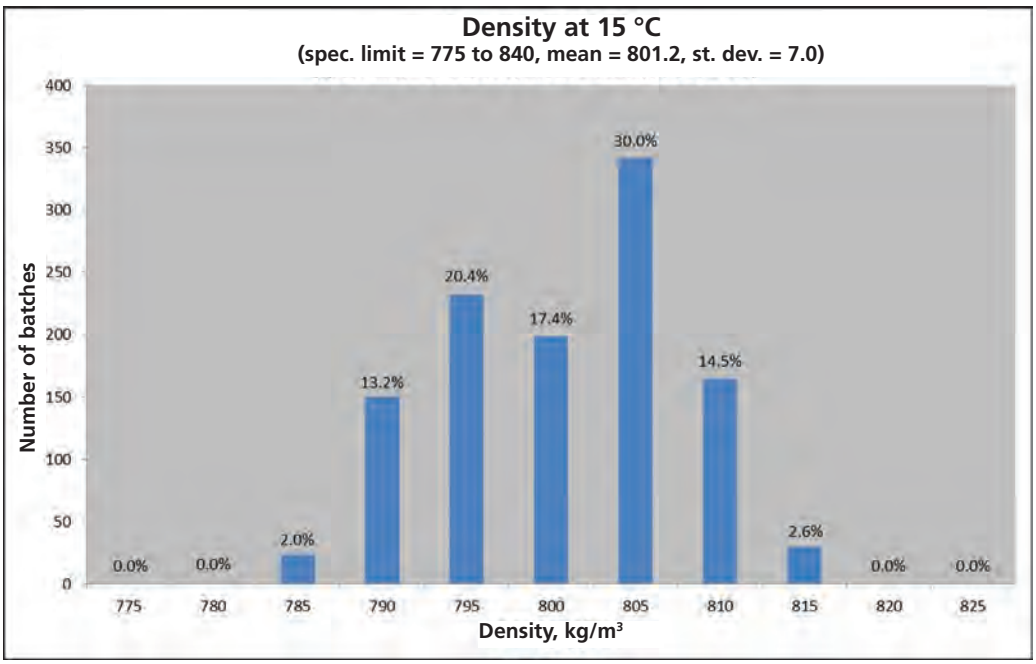

Figure 64: Density histogram 2012

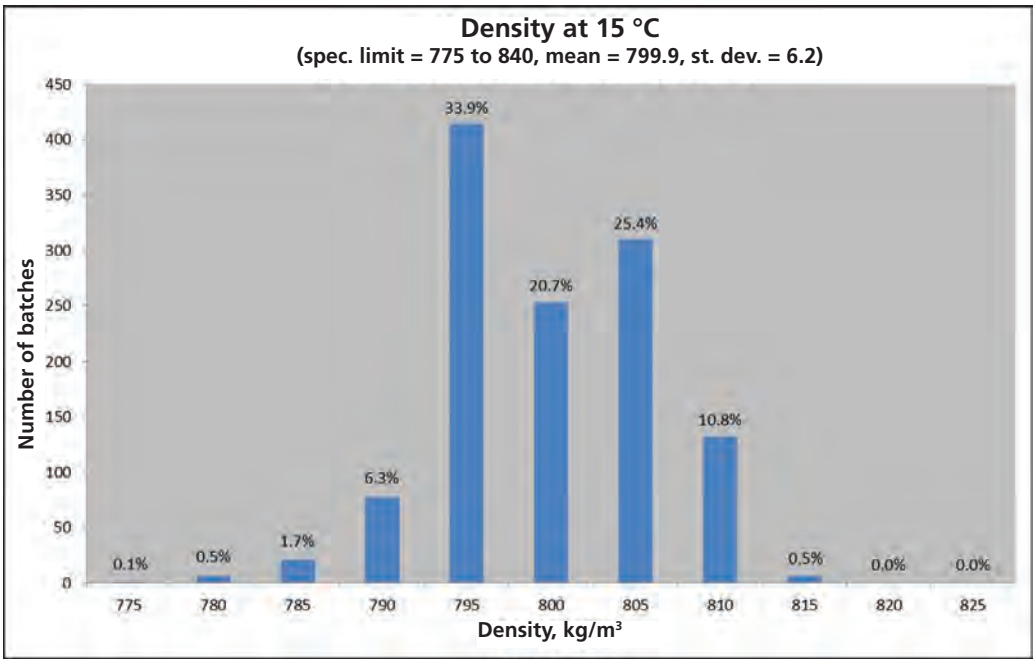

Figure 65: Density histogram 2013

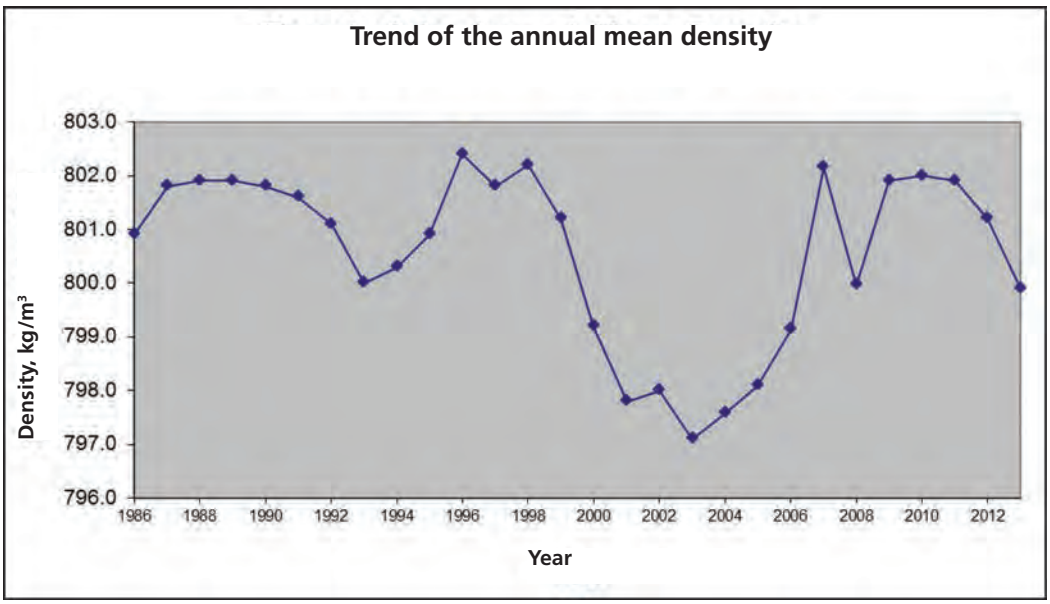

Figure 66: Density trend graph

B.12 FREEZING POINT

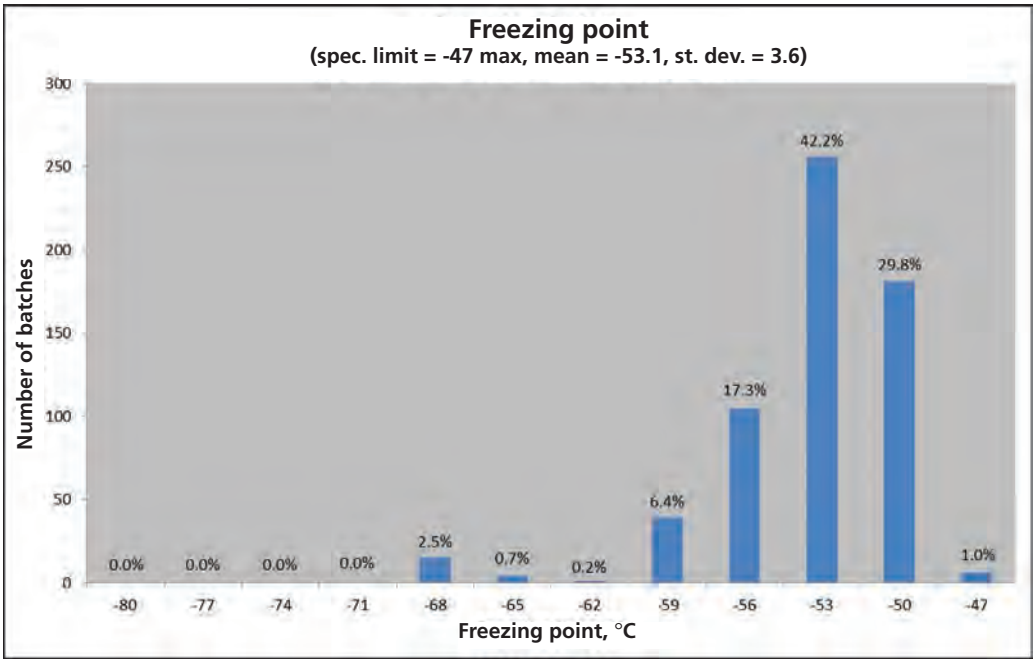

Figure 67: Freezing point histogram 2009

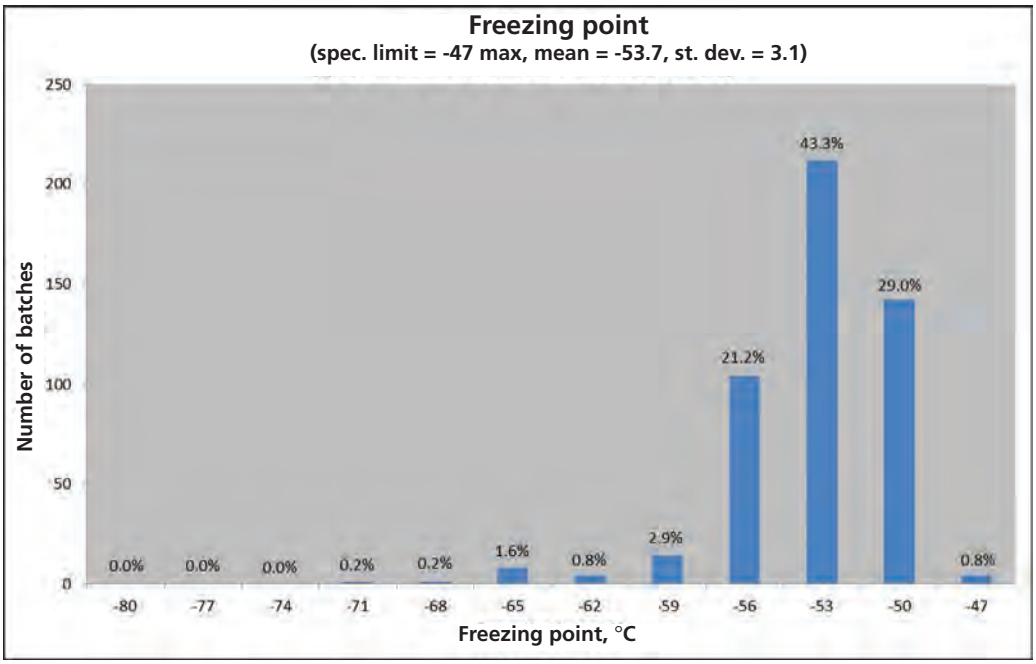

Figure 68: Freezing point histogram 2010

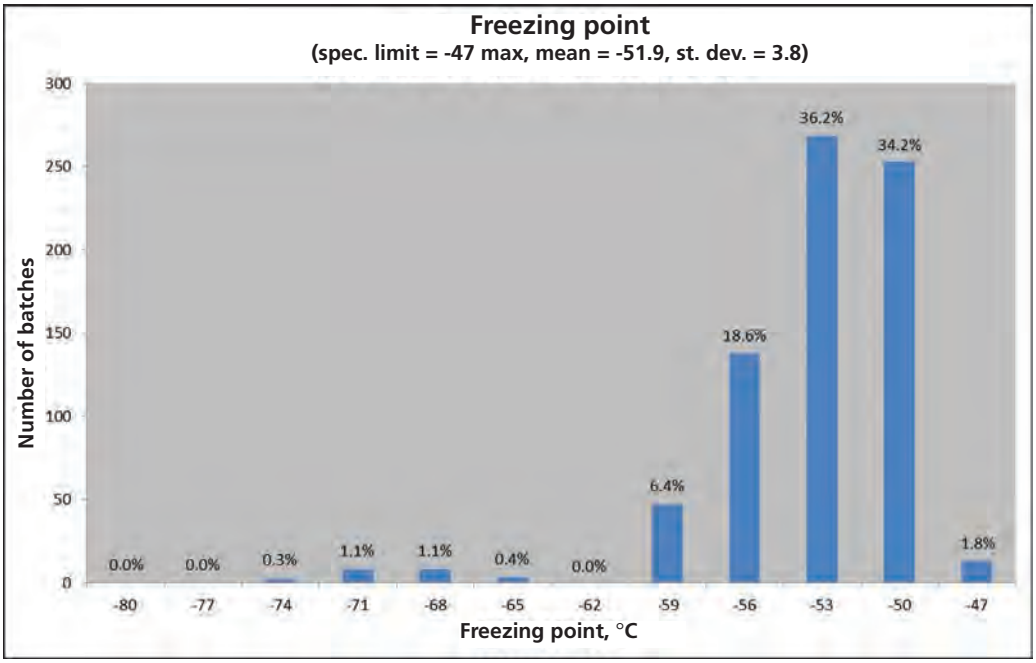

Figure 69: Freezing point histogram 2011

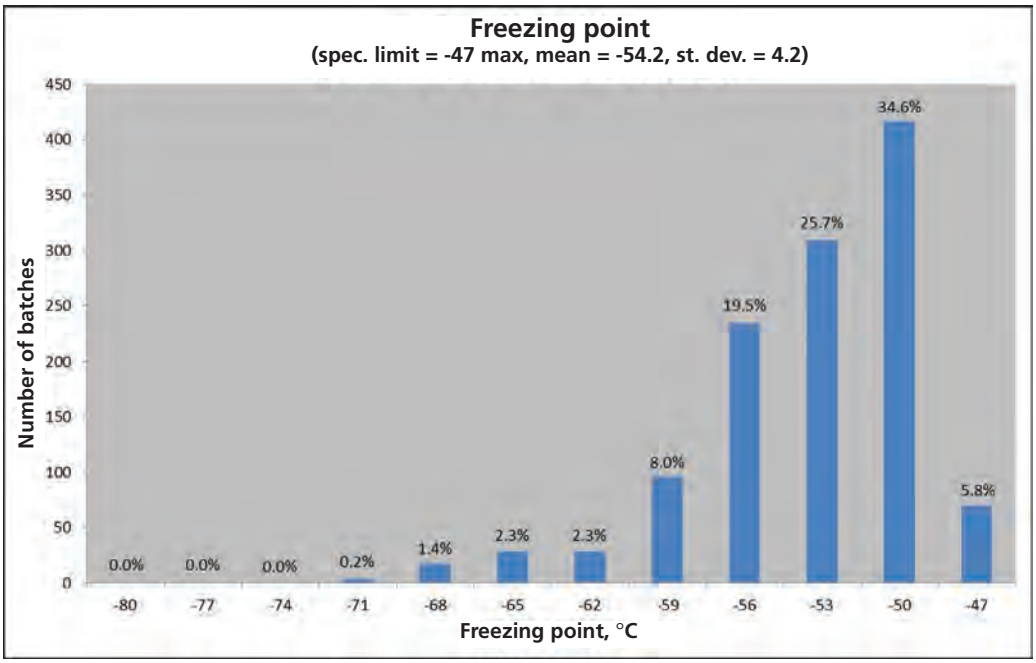

Figure 70: Freezing point histogram 2012

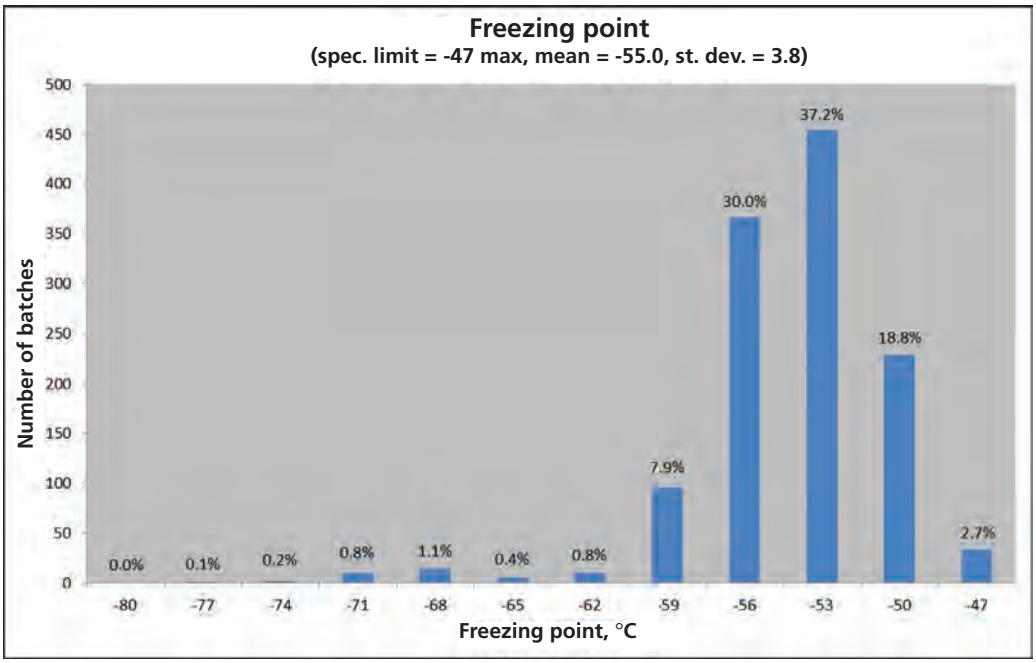

Figure 71: Freezing point histogram 2013

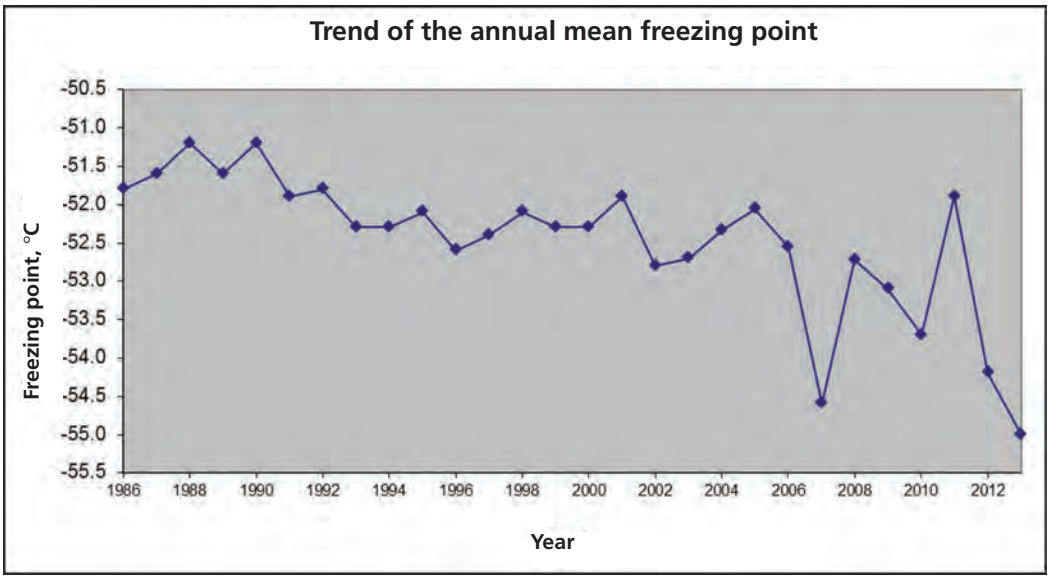

Figure 72: Freezing point trend graph

B.13 KINEMATIC VISCOSITY AT -20 °C

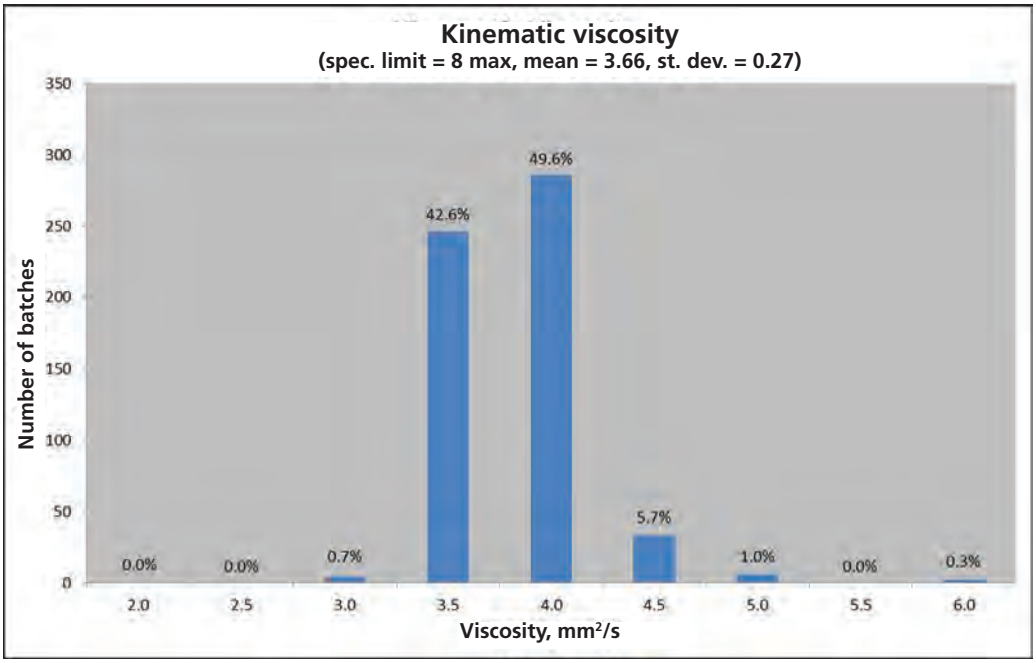

Figure 73: Kinematic viscosity histogram 2009

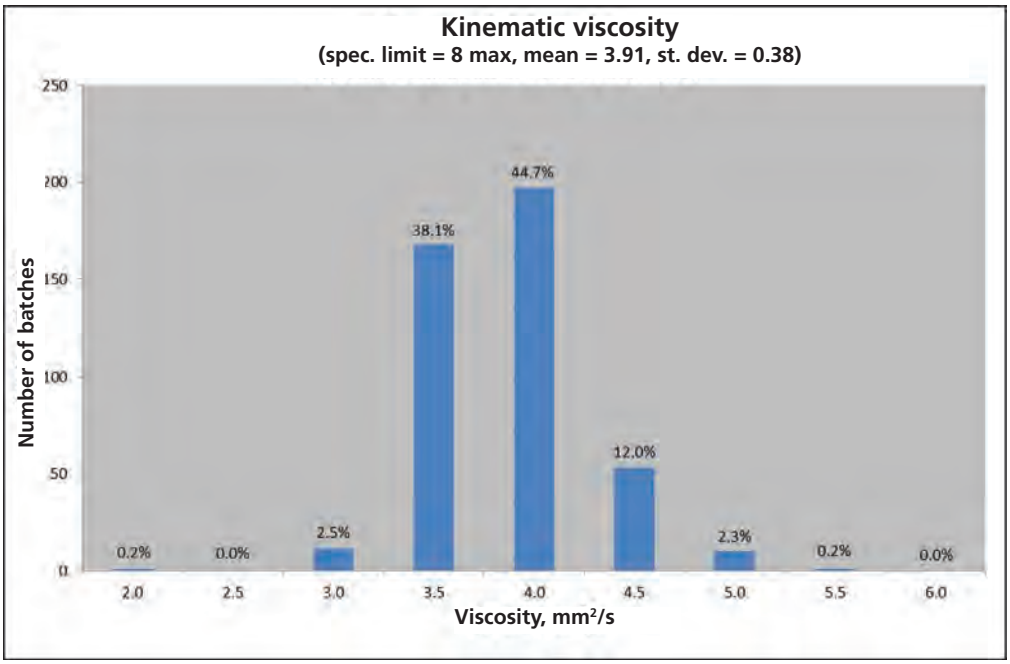

Figure 74: Kinematic viscosity histogram 2010

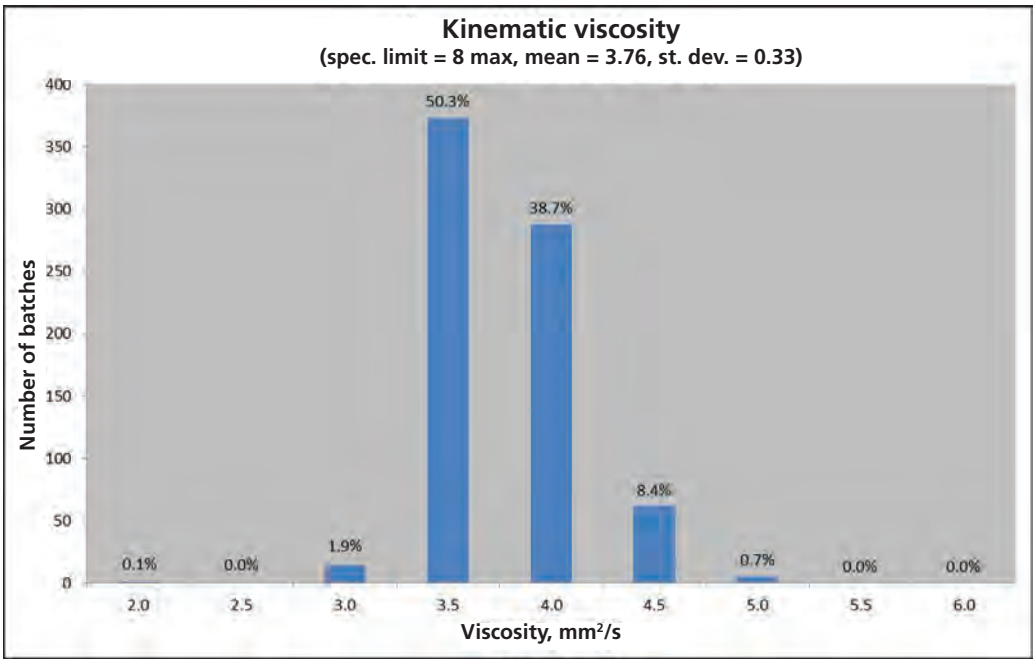

Figure 75: Kinematic viscosity histogram 2011

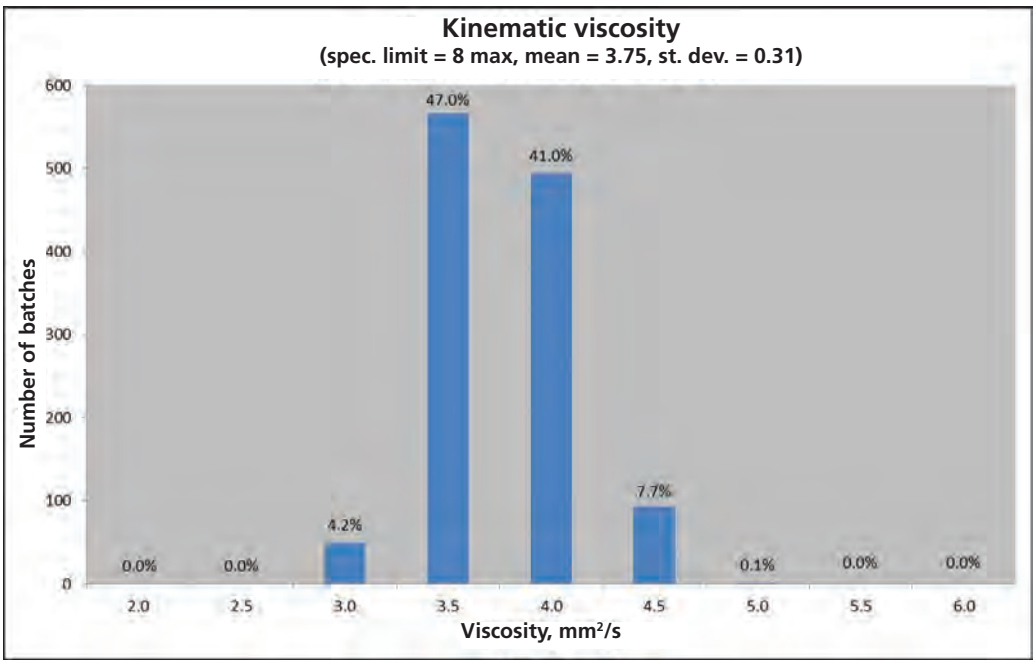

Figure 76: Kinematic viscosity histogram 2012

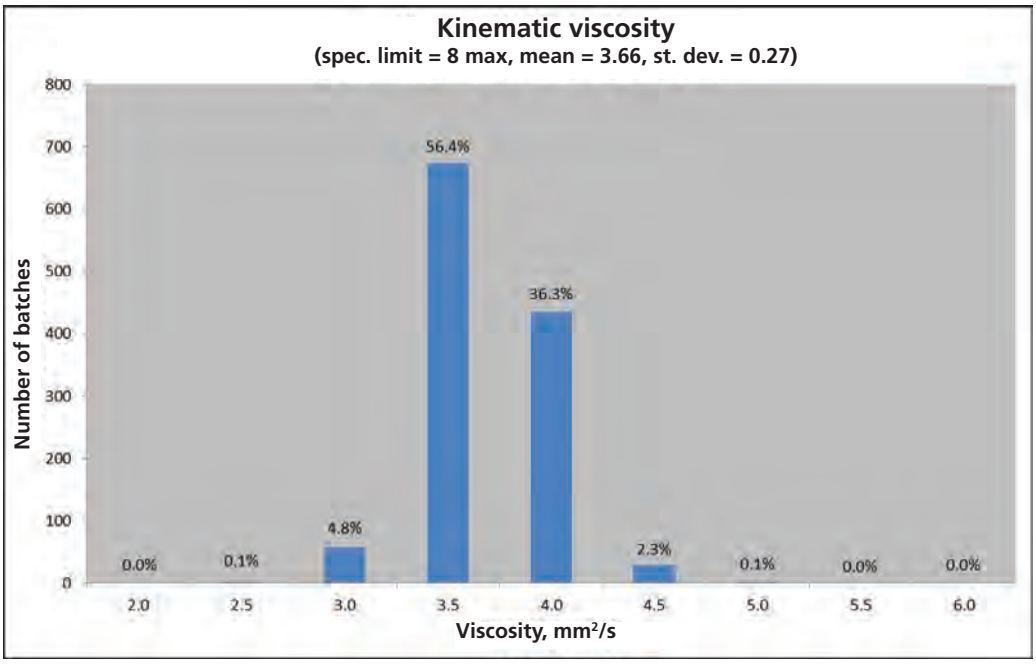

Figure 77: Kinematic viscosity histogram 2013

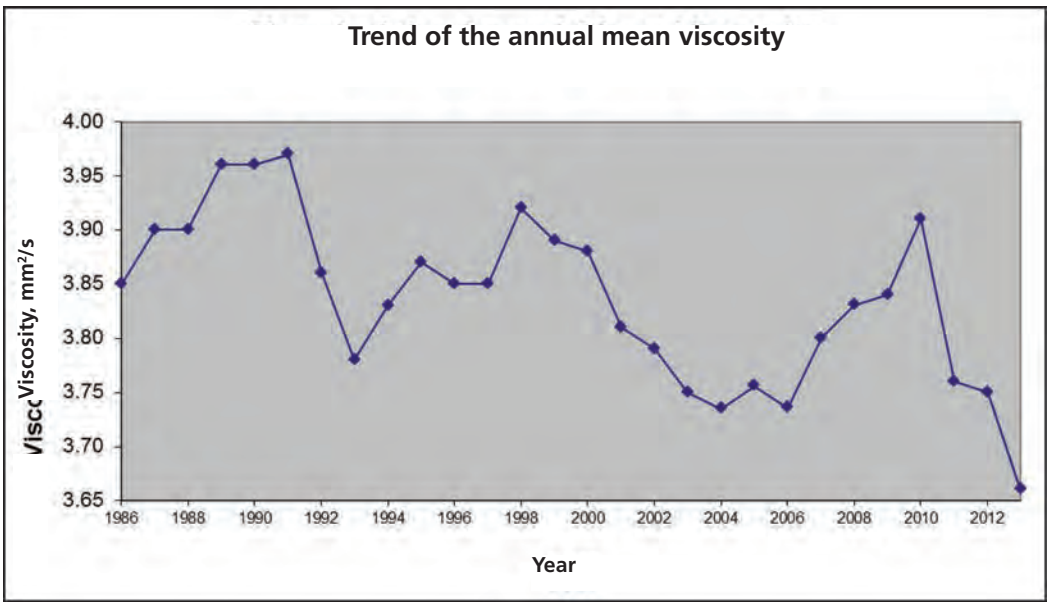

Figure 78: Kinematic viscosity trend graph

B.14 SPECIFIC ENERGY

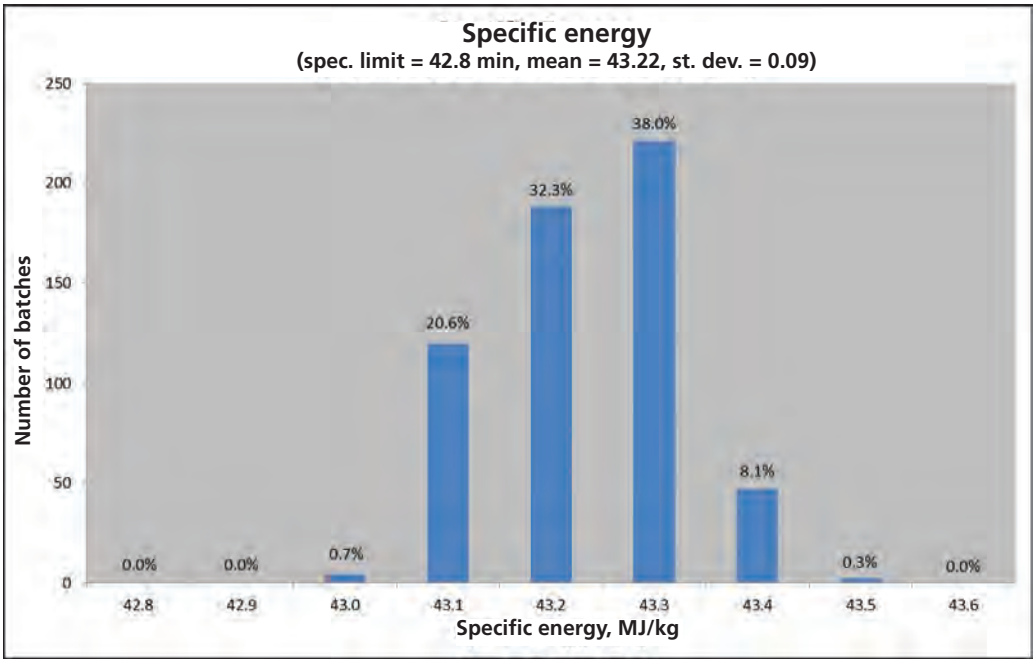

Figure 79: Specific energy histogram 2009

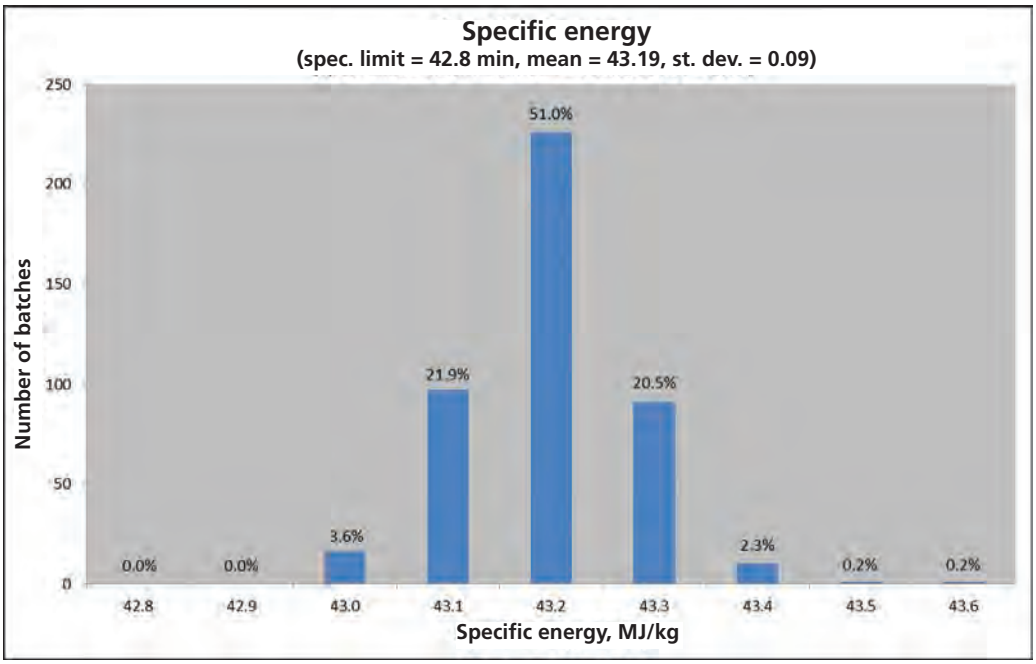

Figure 80: Specific energy histogram 2010

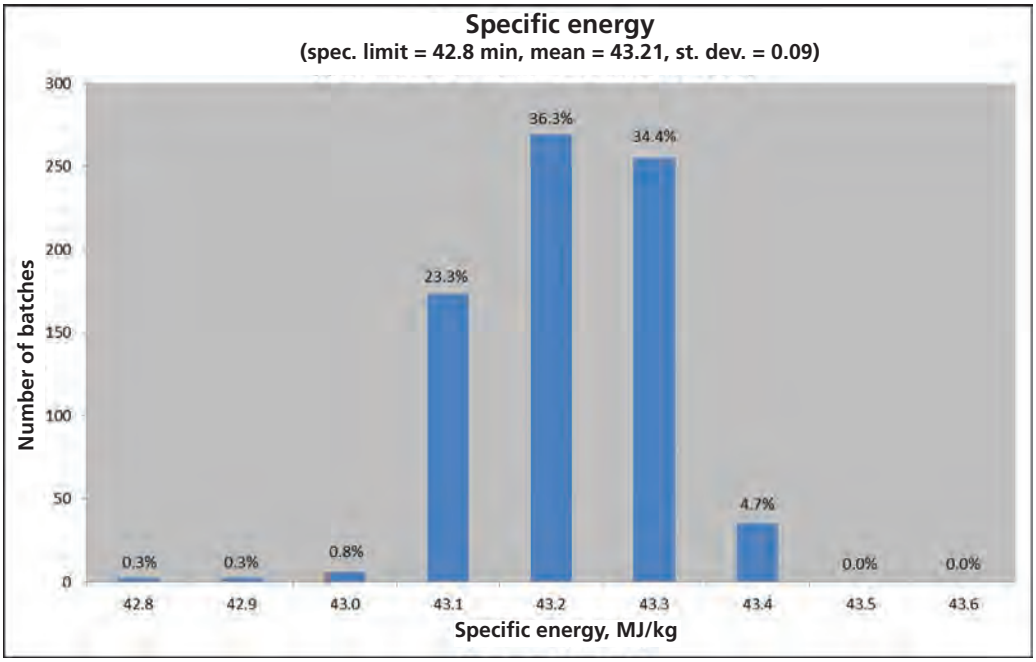

Figure 81: Specific energy histogram 2011

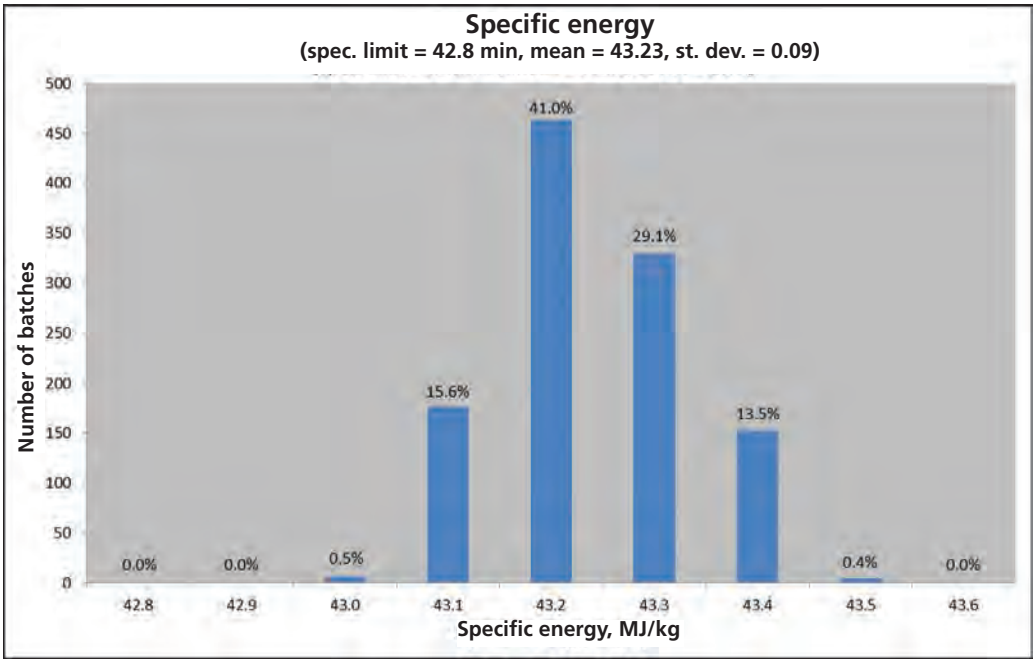

Figure 82: Specific energy histogram 2012

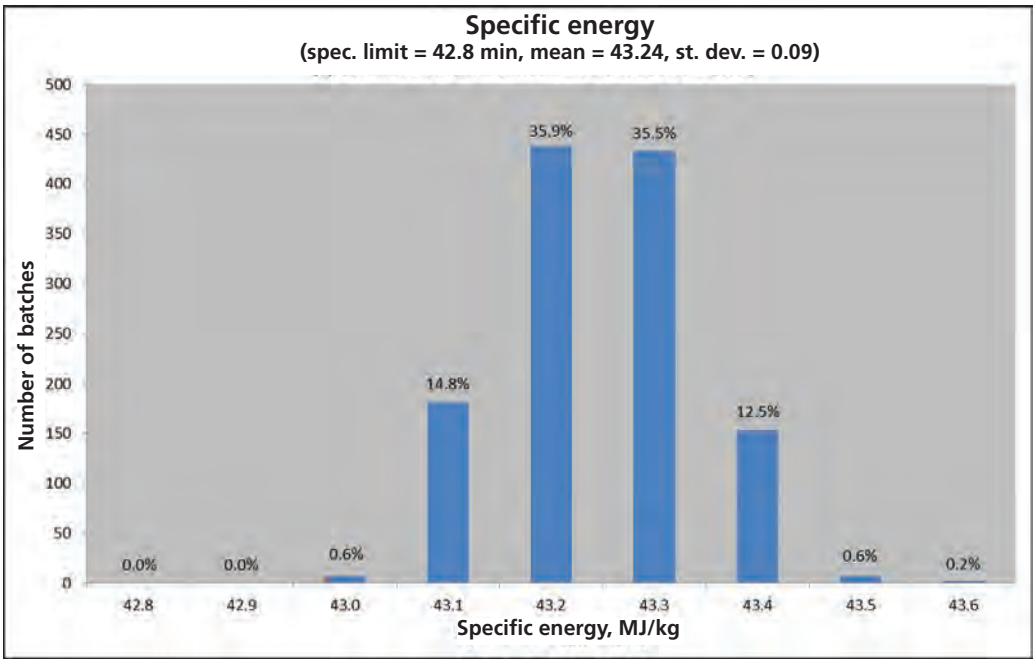

Figure 83: Specific energy histogram 2013

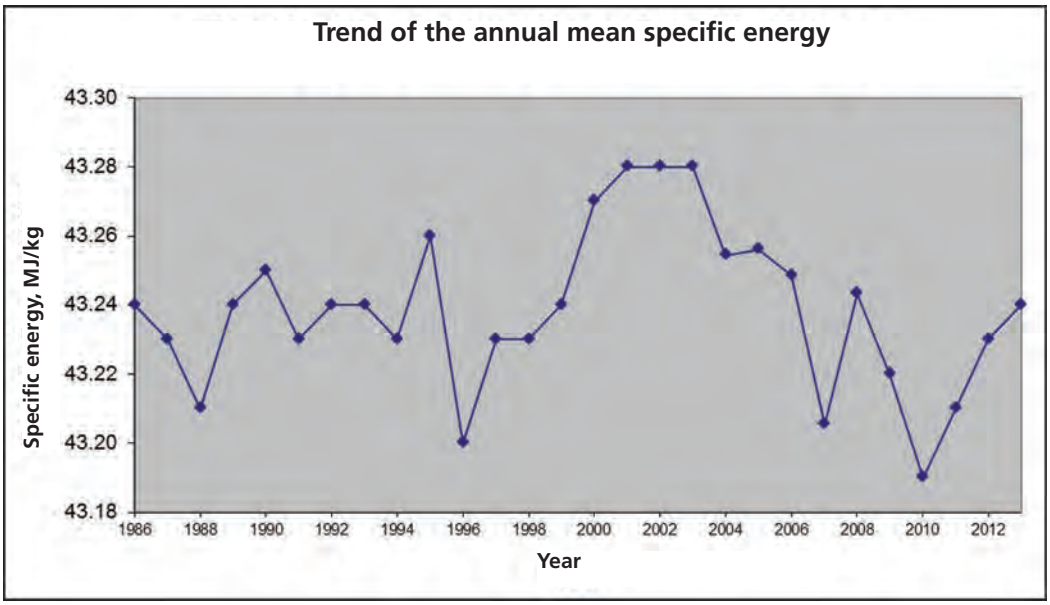

Figure 84: Specific energy trend graph

B.15 SMOKE POINT

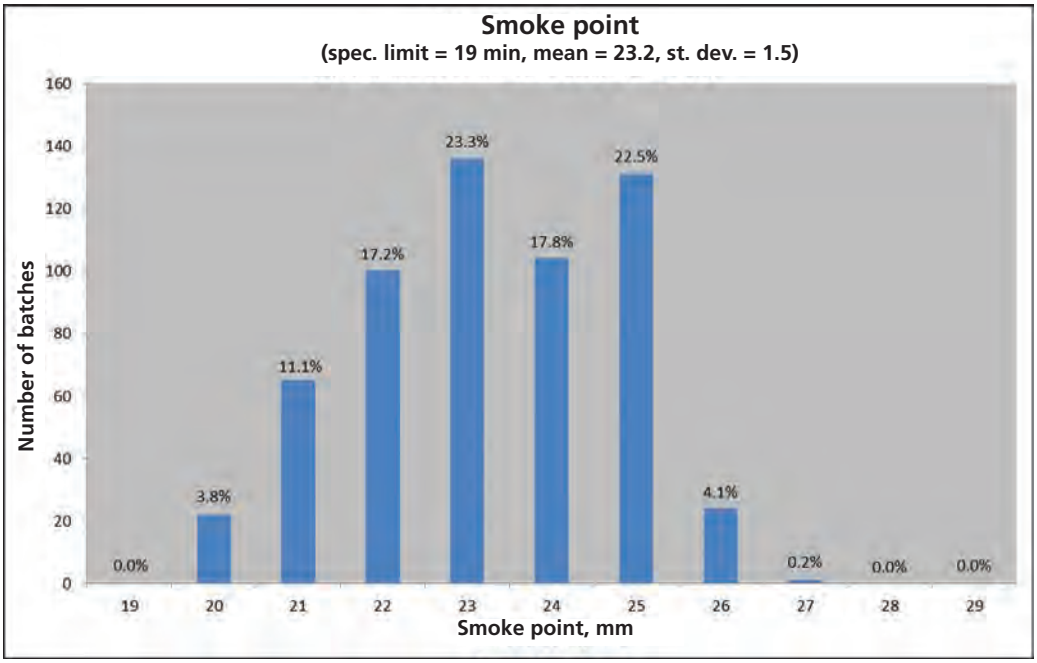

Figure 85: Smoke point histogram 2009

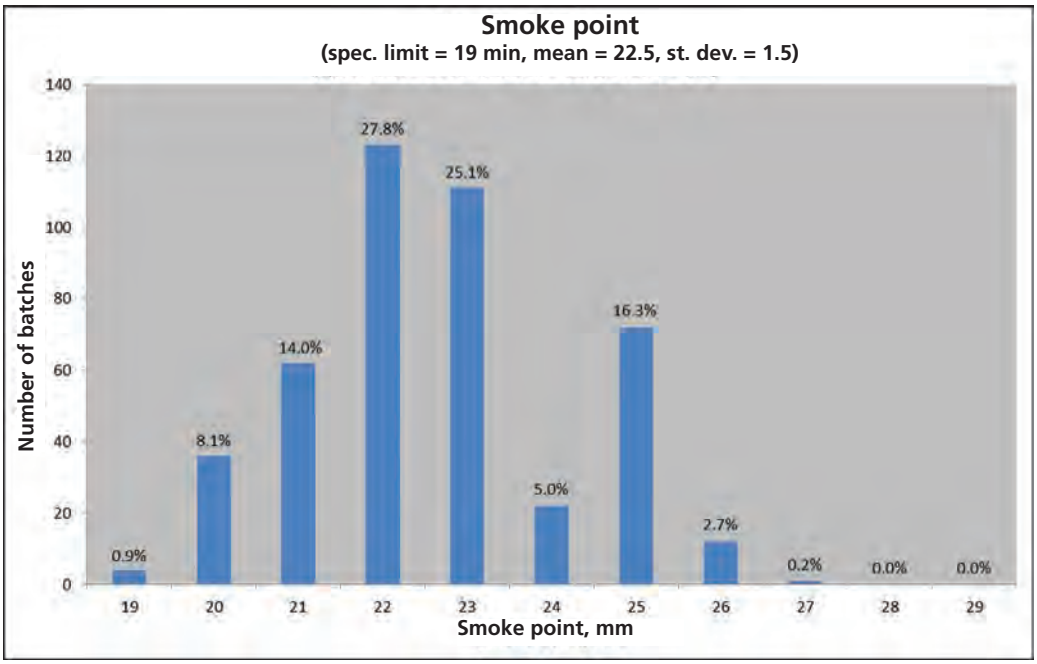

Figure 86: Smoke point histogram 2010

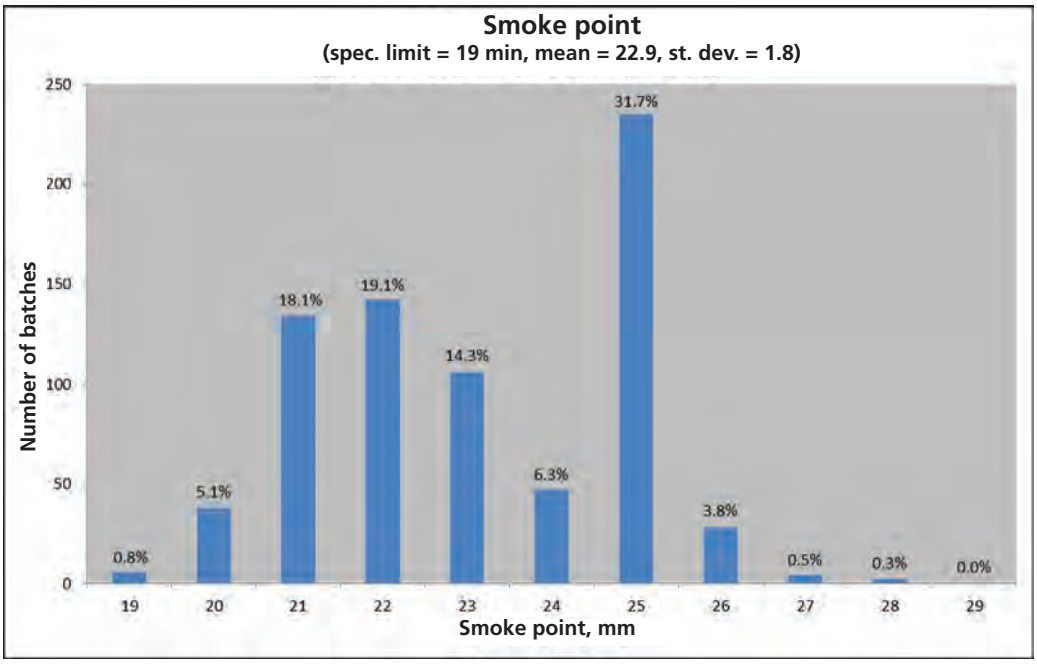

Figure 87: Smoke point histogram 2011

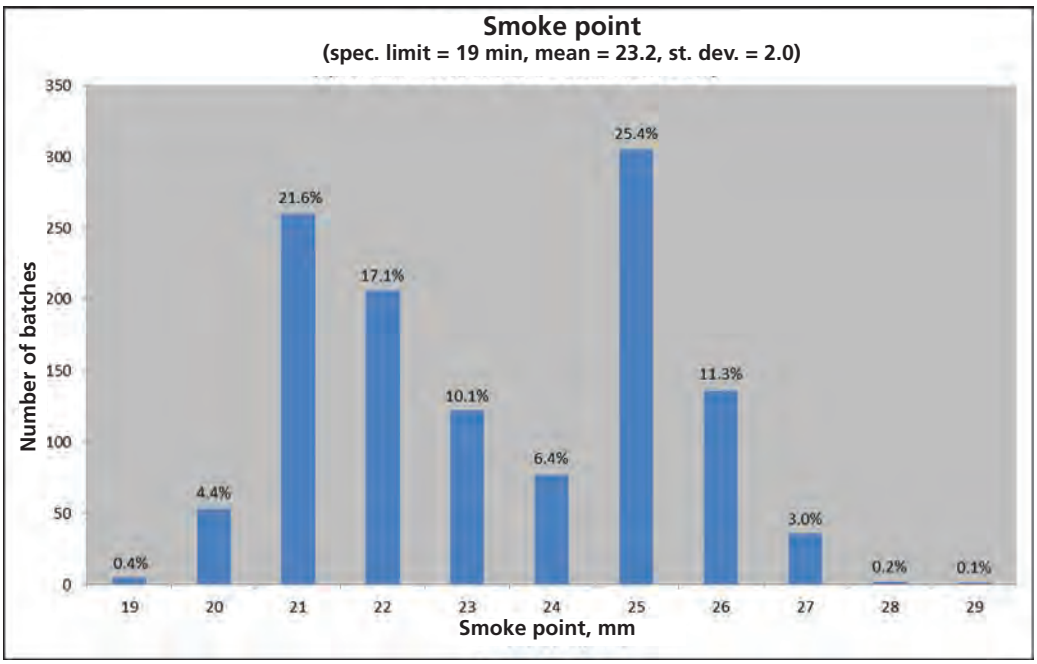

Figure 88: Smoke point histogram 2012

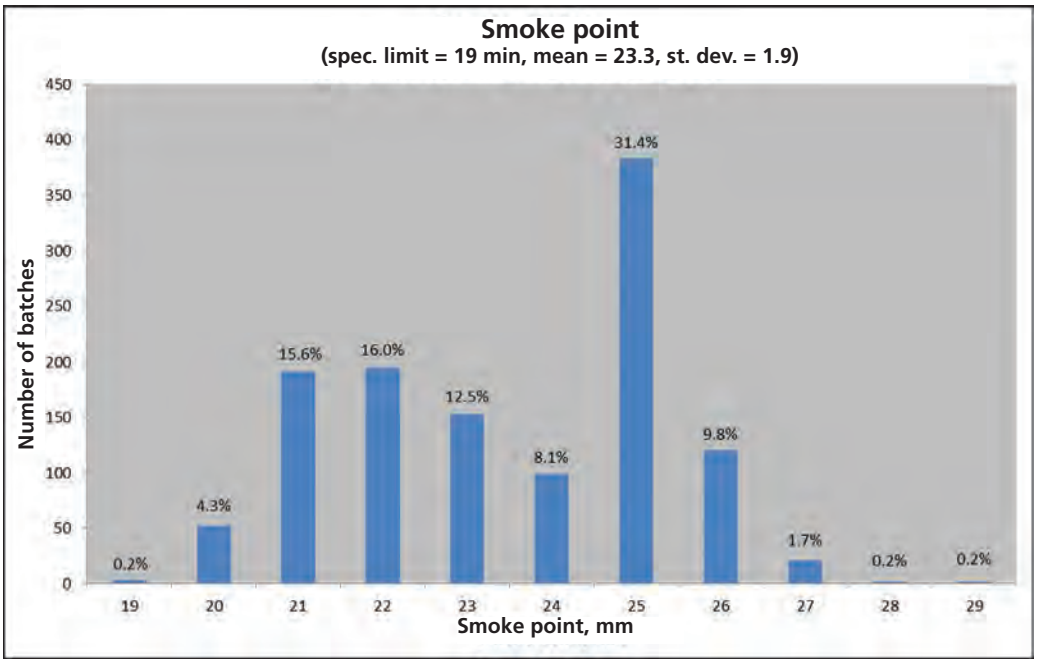

Figure 89: Smoke point histogram 2013

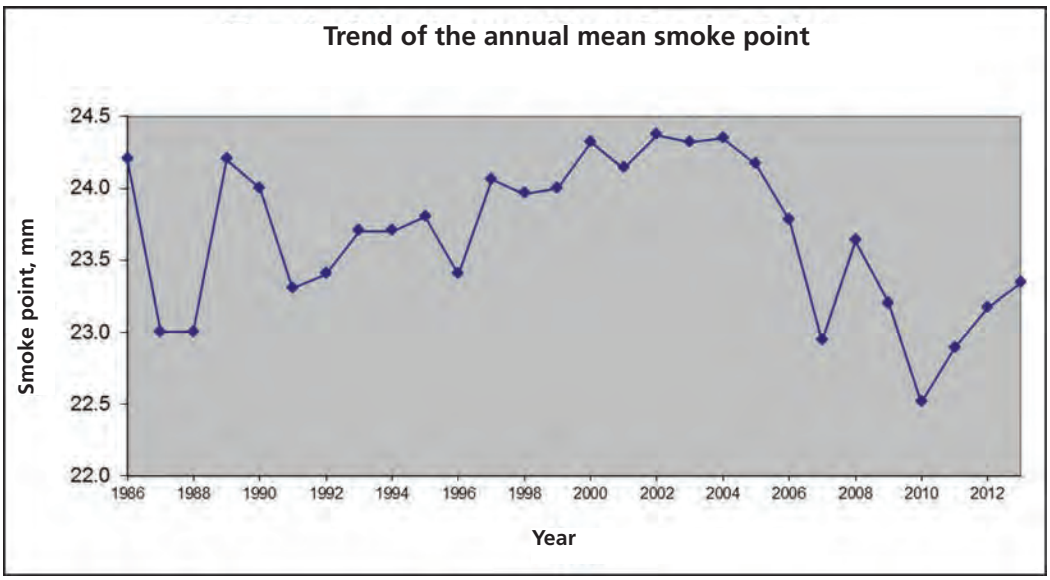

Figure 90: Smoke point trend graph

B.16 NAPHTHALENES

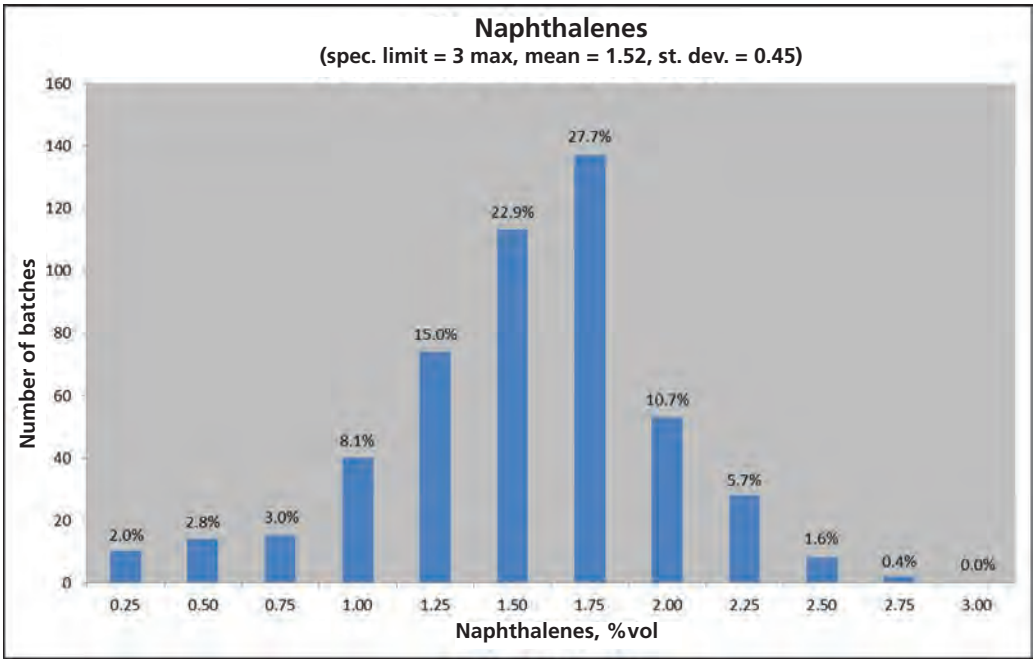

Figure 91: Naphthalenes histogram 2009

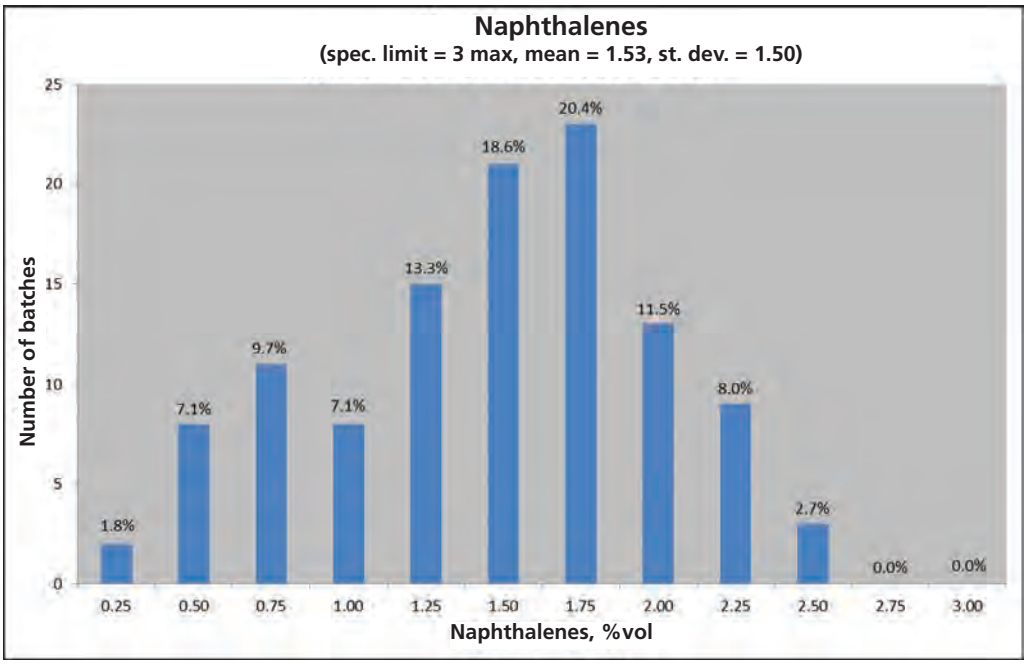

Figure 92: Naphthalenes histogram 2010

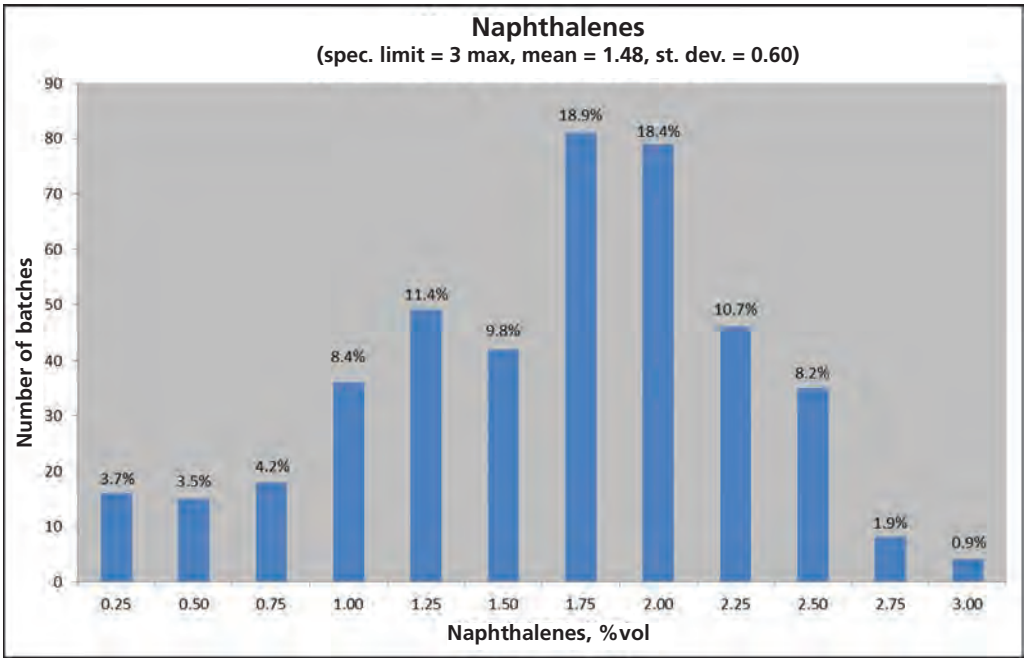

Figure 93: Naphthalenes histogram 2011

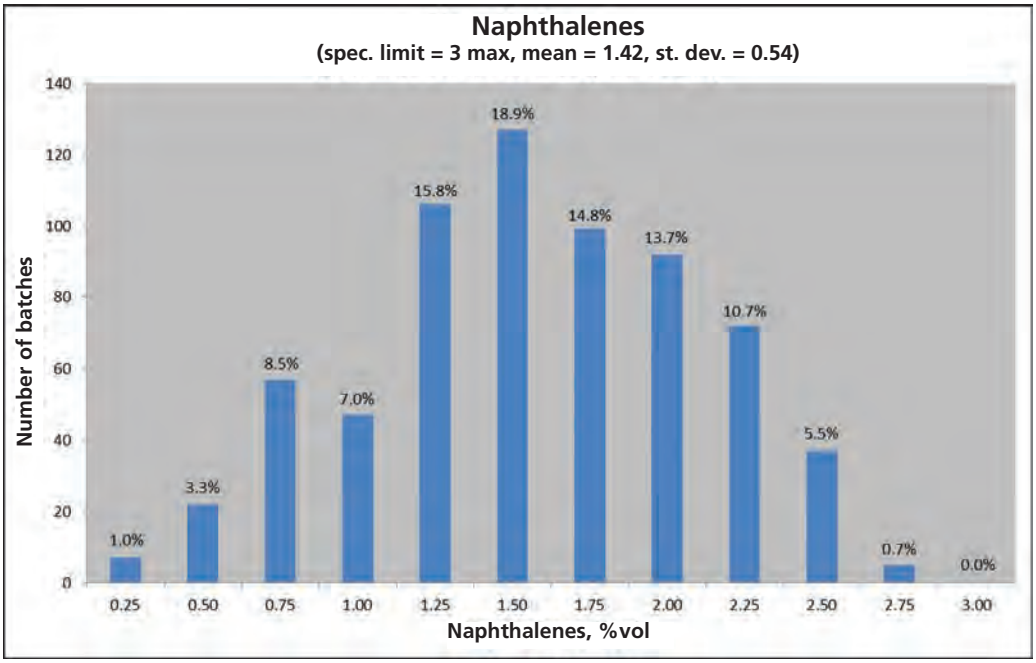

Figure 94: Naphthalenes histogram 2012

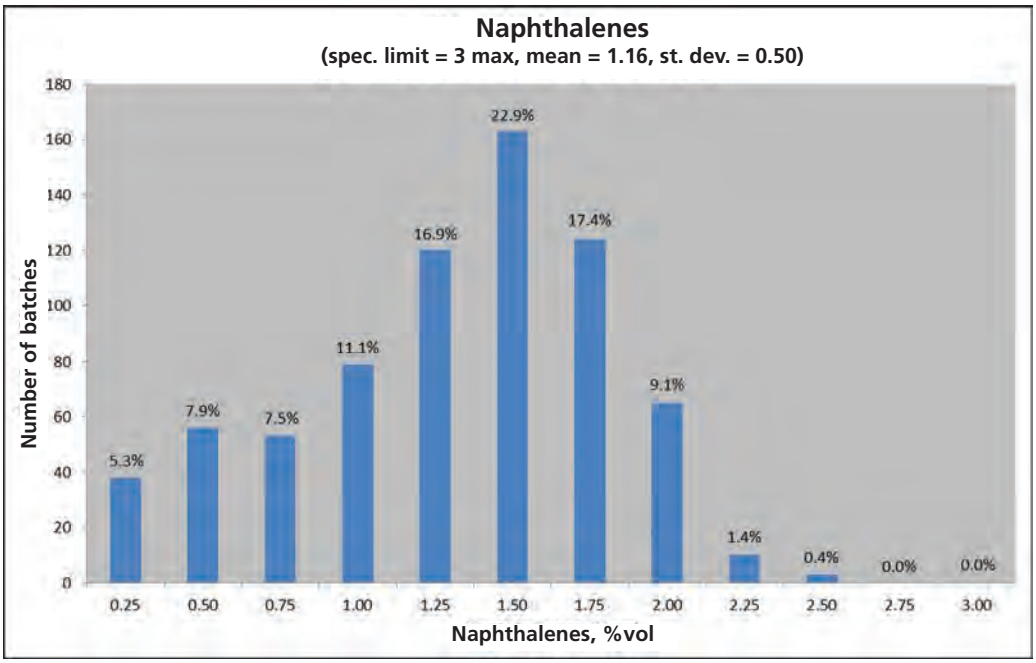

Figure 95: Naphthalenes histogram 2013

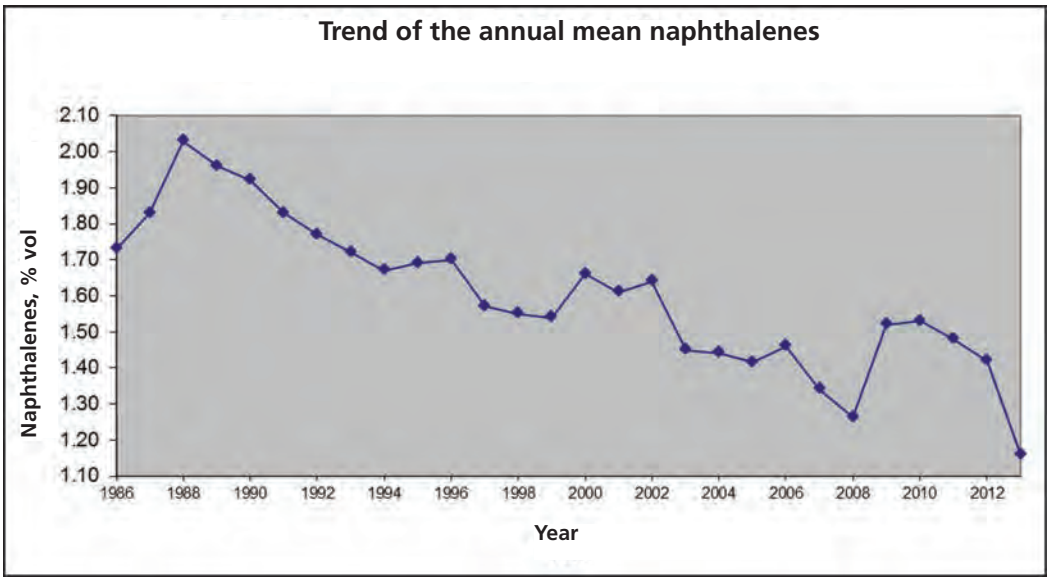

Figure 96: Naphthalenes trend graph

B.17 EXISTENT GUM

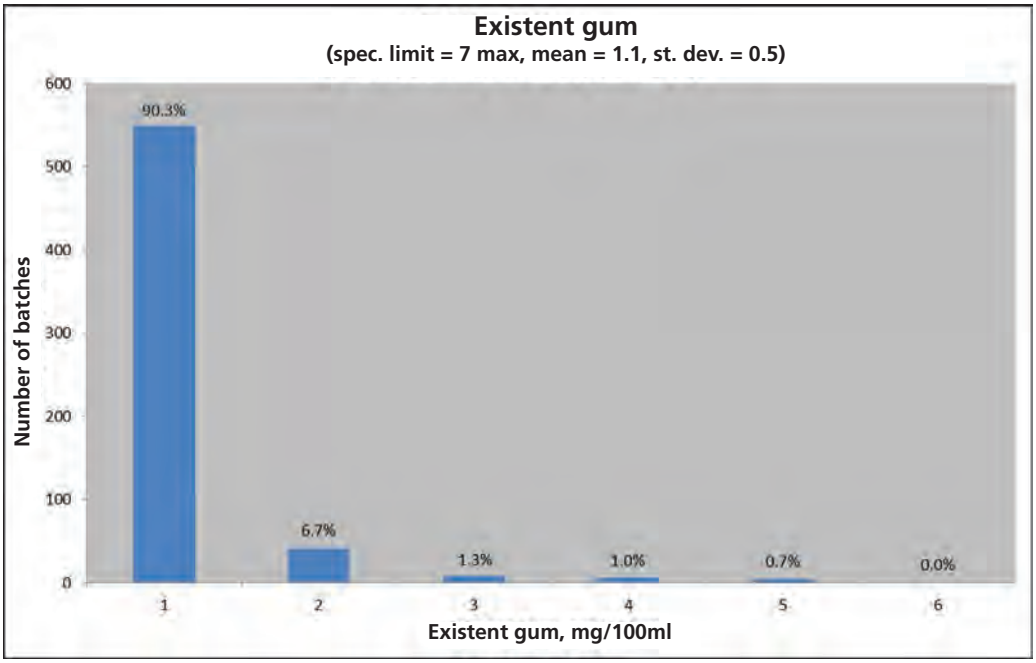

Figure 97: Existent gum histogram 2009

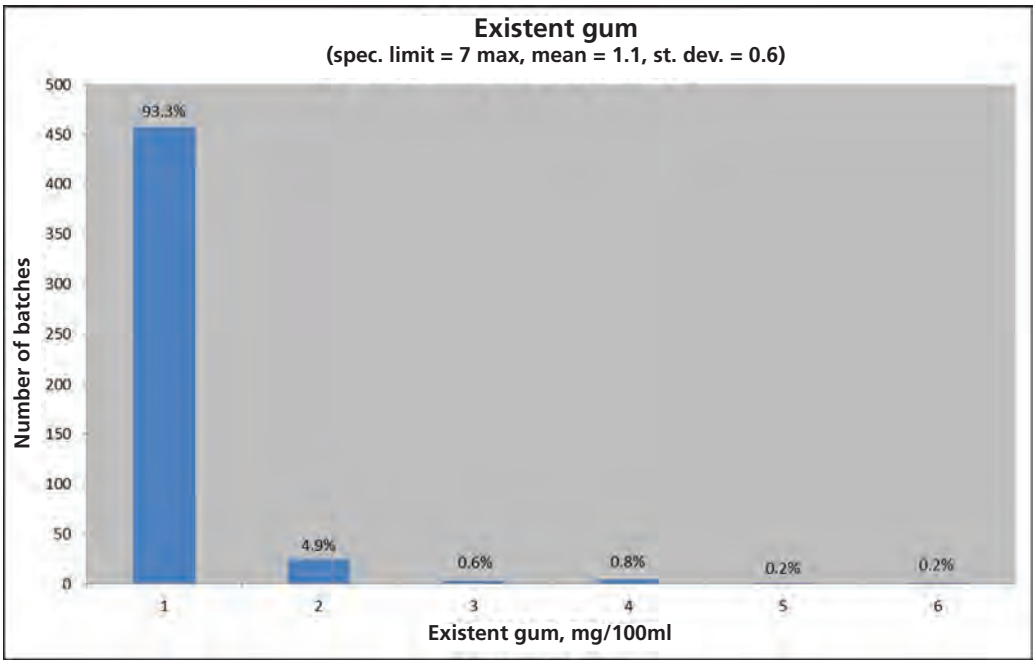

Figure 98: Existent gum histogram 2010

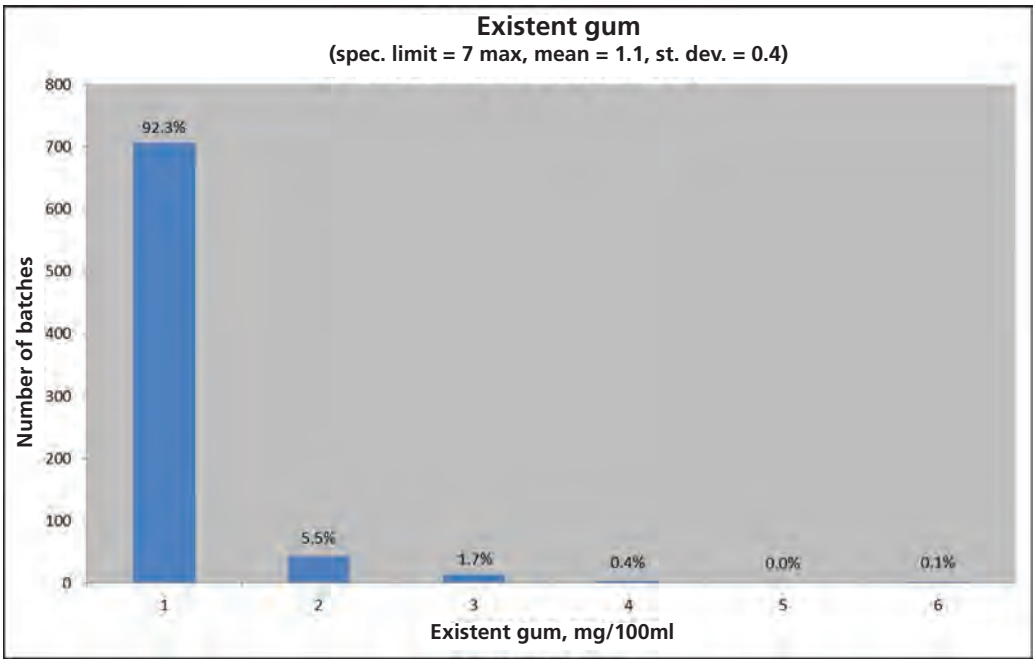

Figure 99: Existent gum histogram 2011

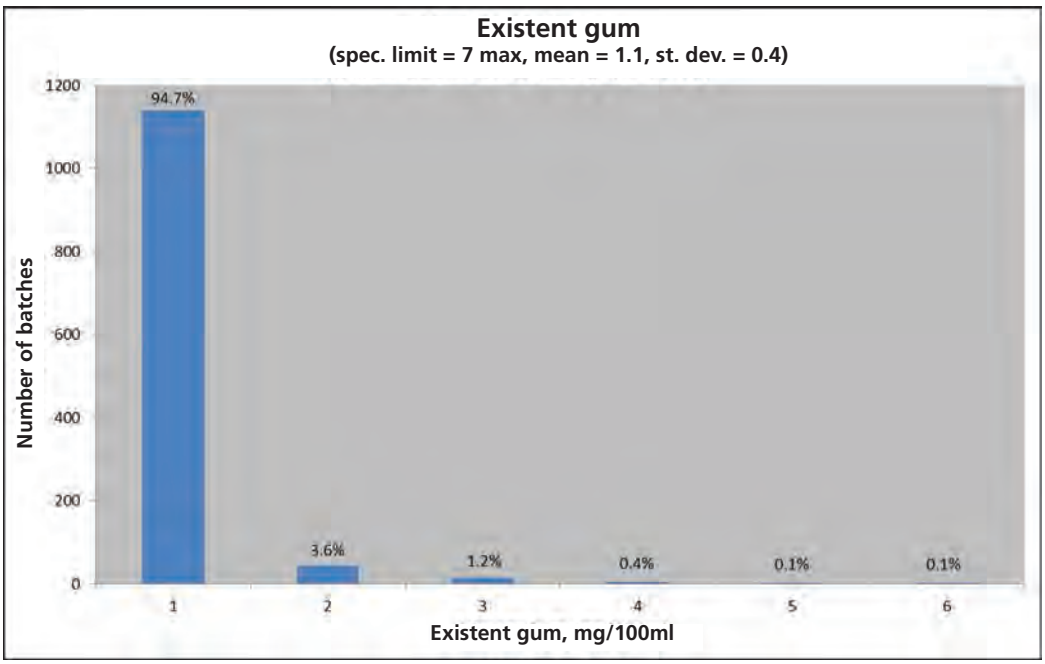

Figure 100: Existent gum histogram 2012

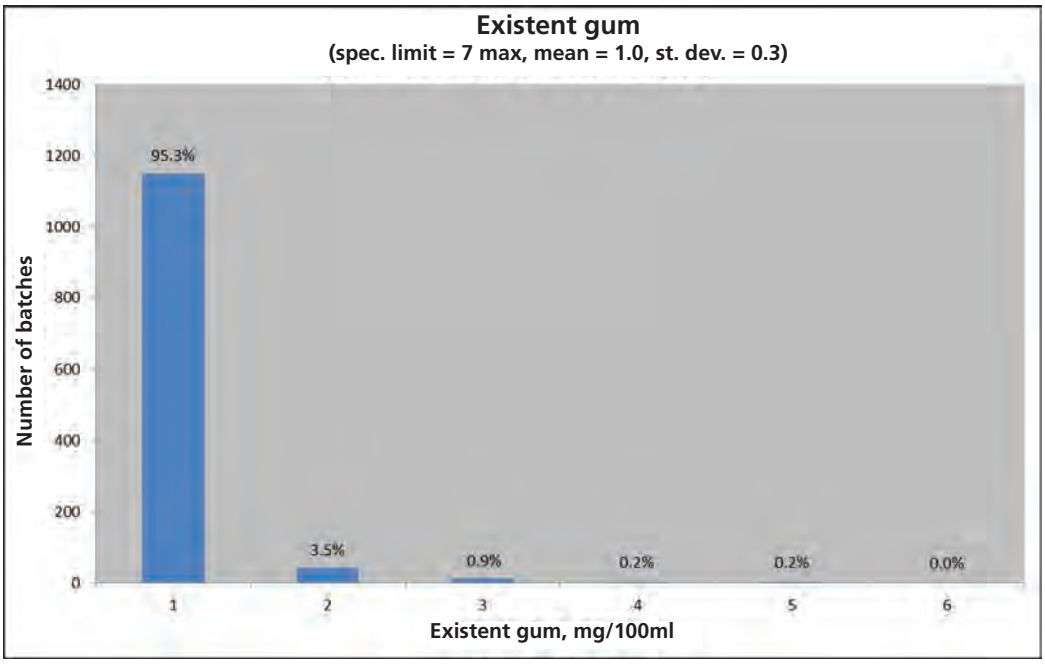

Figure 101: Existent gum histogram 2013

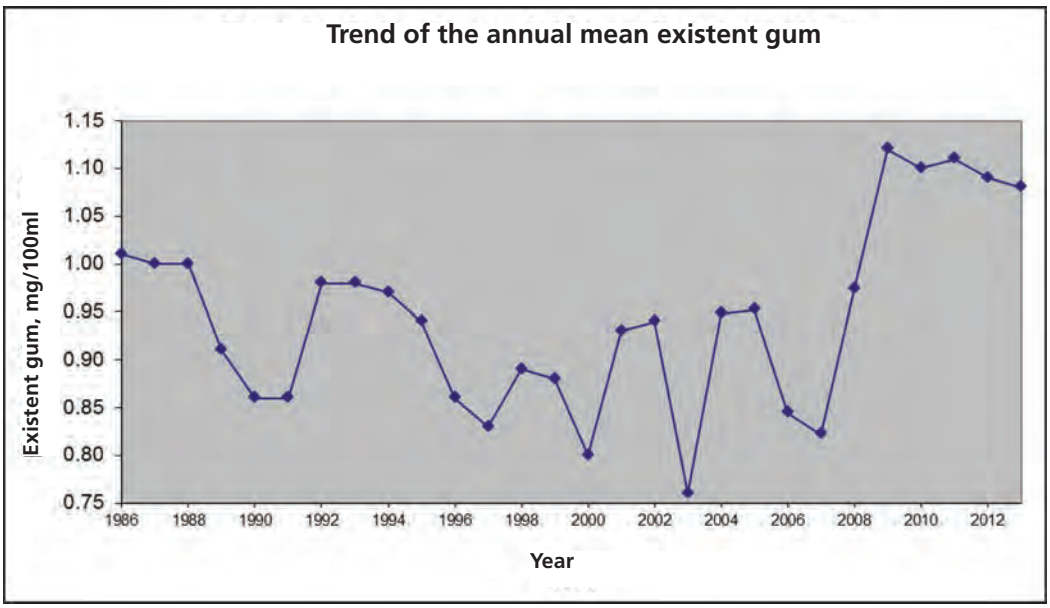

Figure 102: Existent gum trend graph

B.18 MSEP

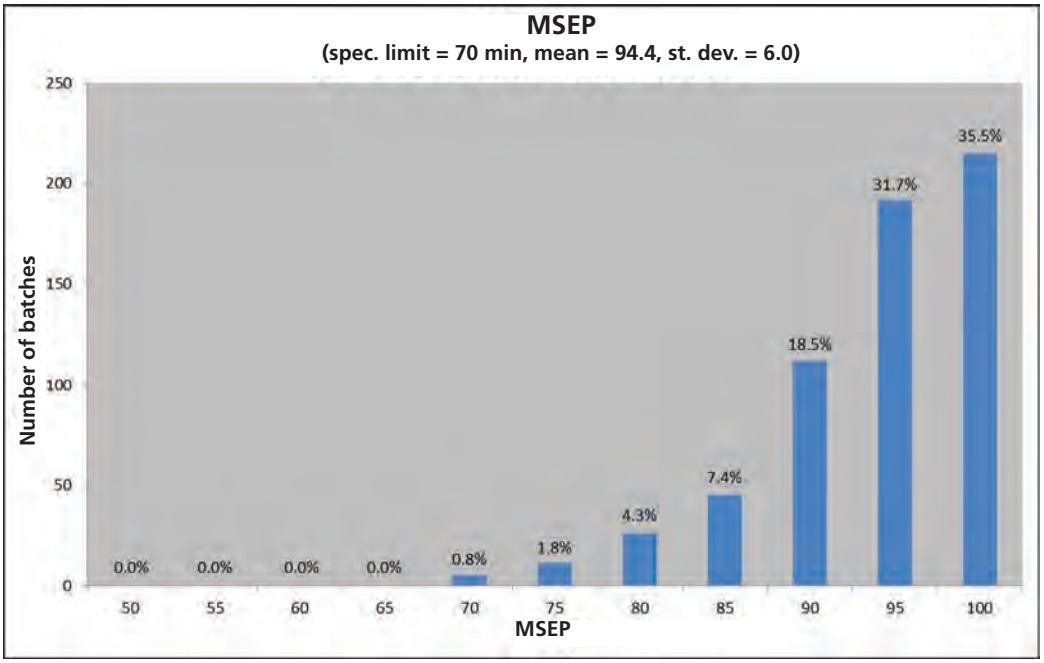

Figure 103: MSEP histogram 2009

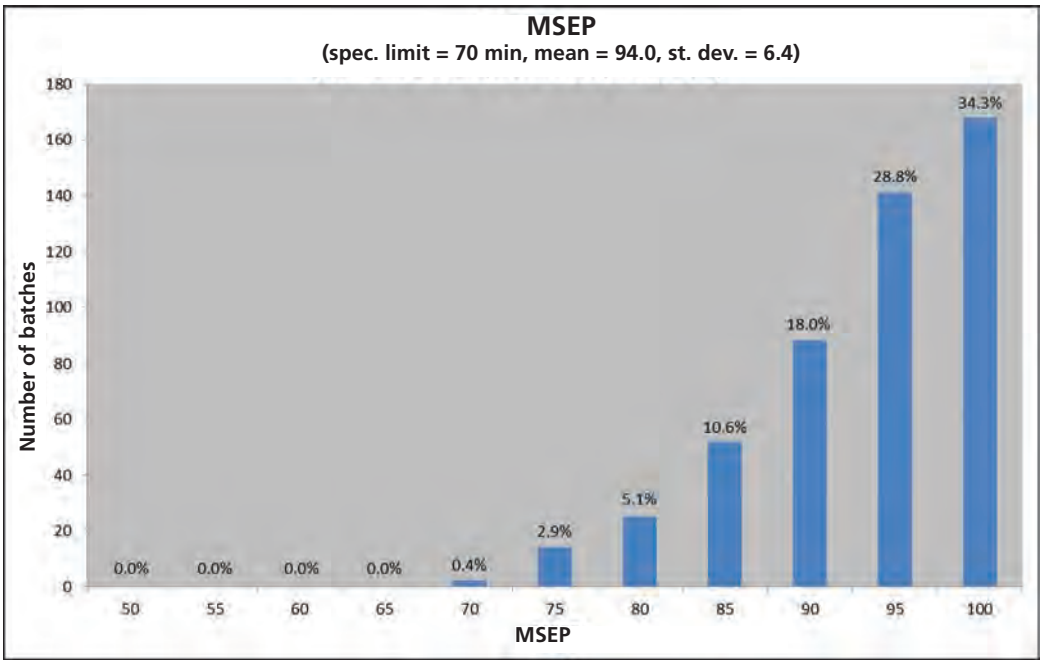

Figure 104: MSEP histogram 2010

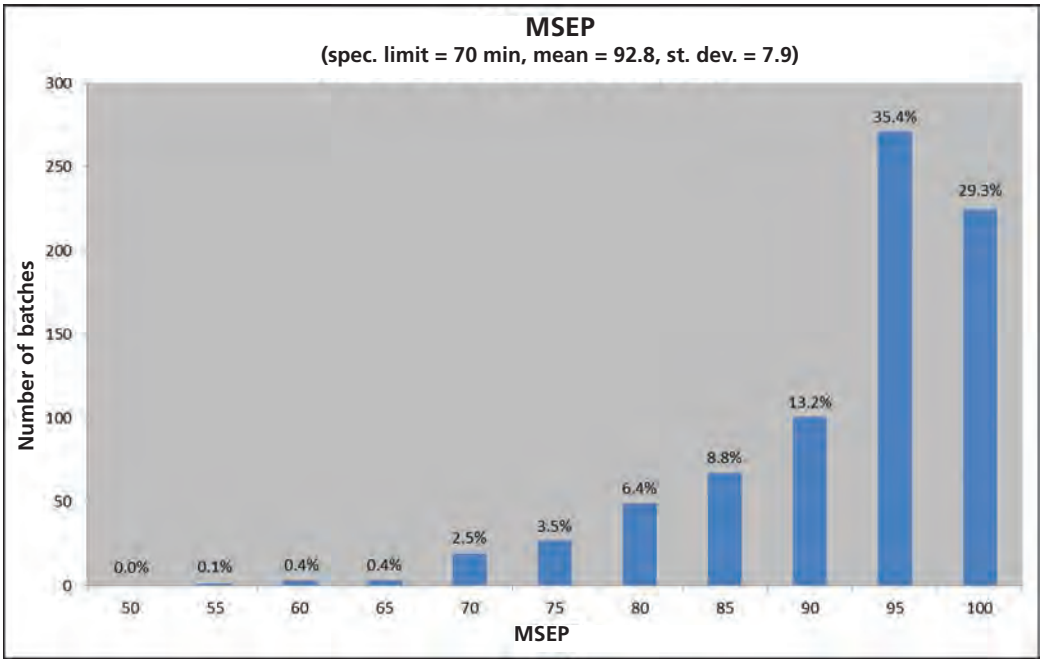

Figure 105: MSEP histogram 2011

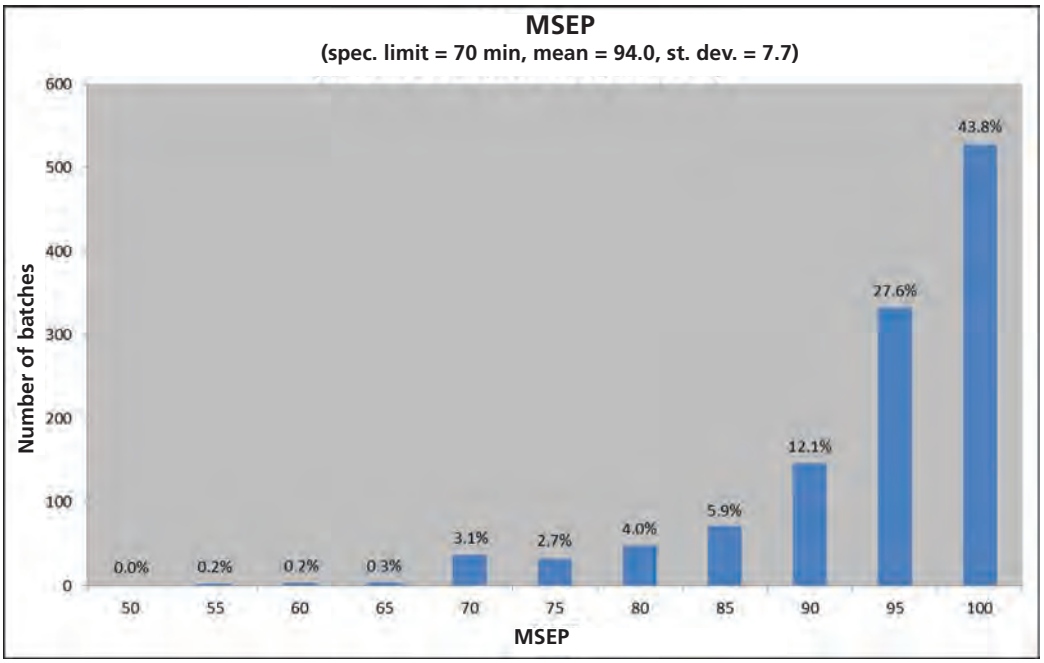

Figure 106: MSEP histogram 2012

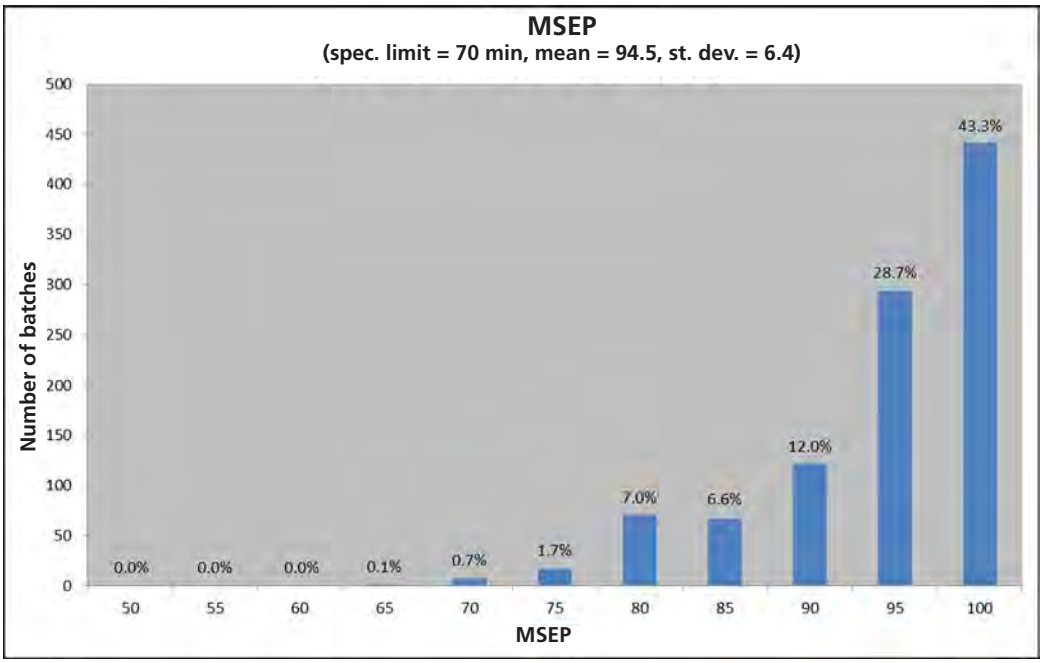

Figure 107: MSEP histogram 2013

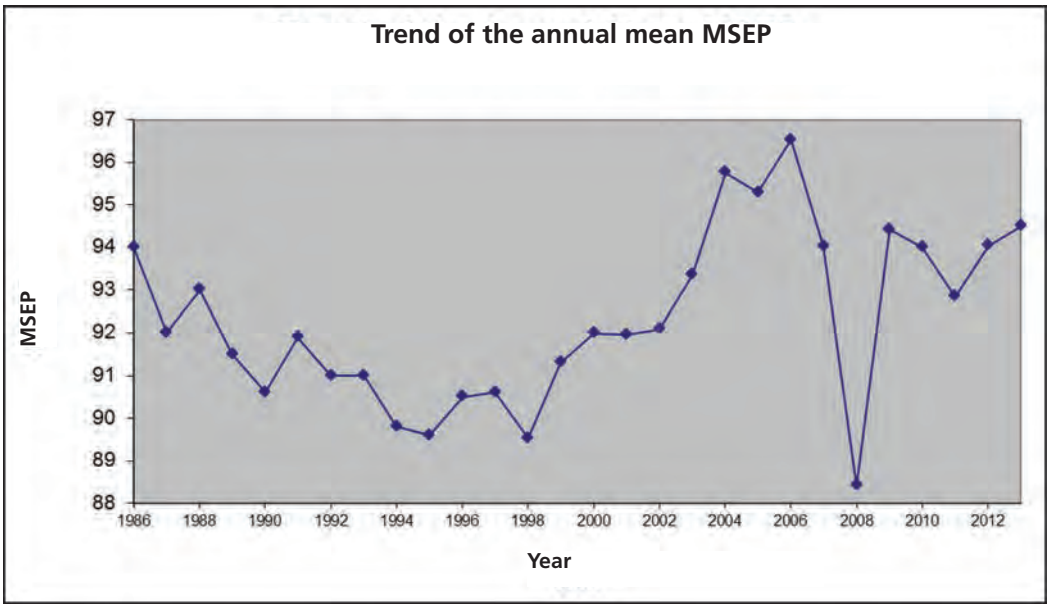

Figure 108: MSEP trend graph

B.19 PARTICULATE (GRAVIMETRIC)

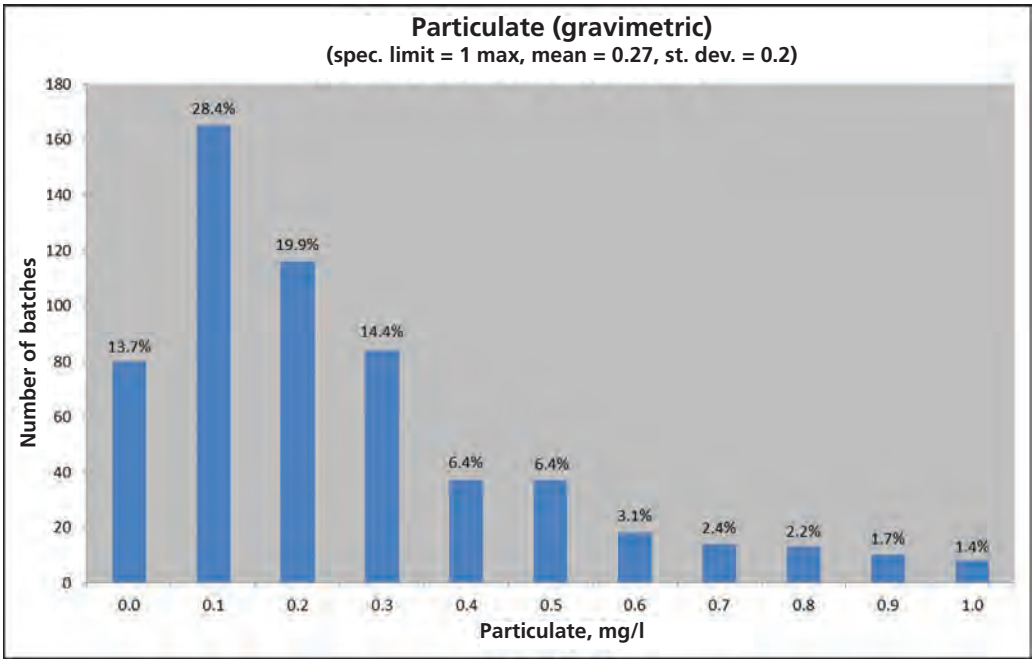

Figure 109: Particulate histogram 2009

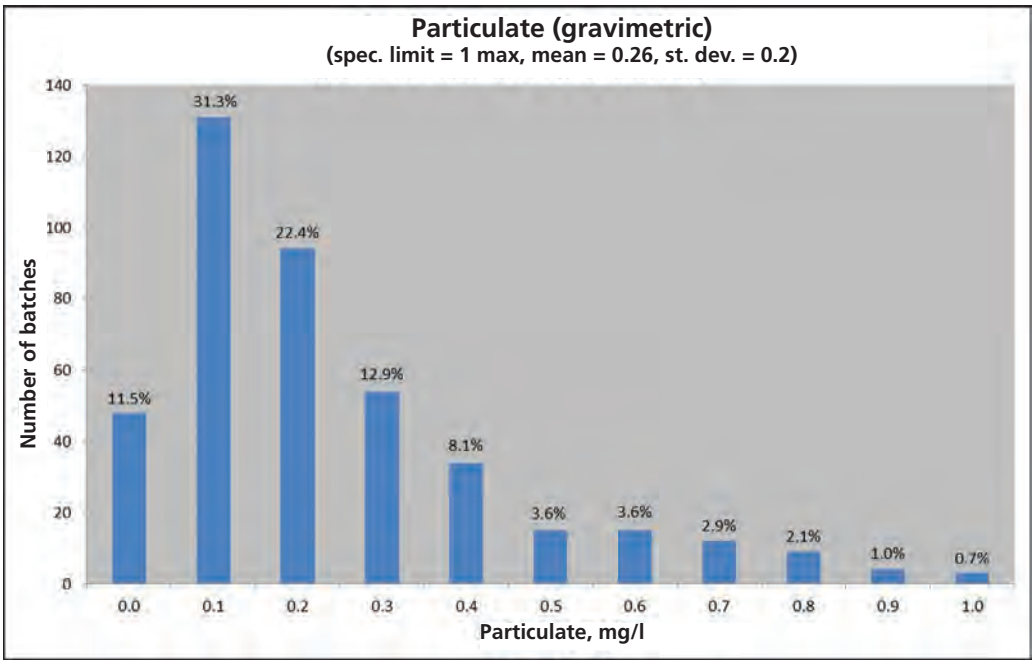

Figure 110: Particulate histogram 2010

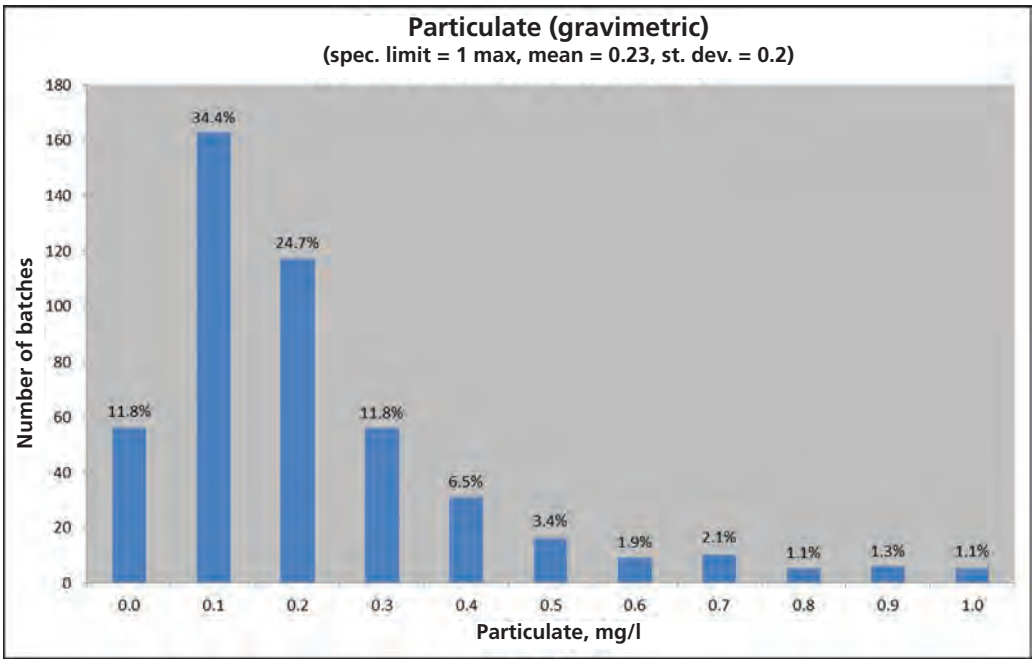

Figure 111: Particulate histogram 2011

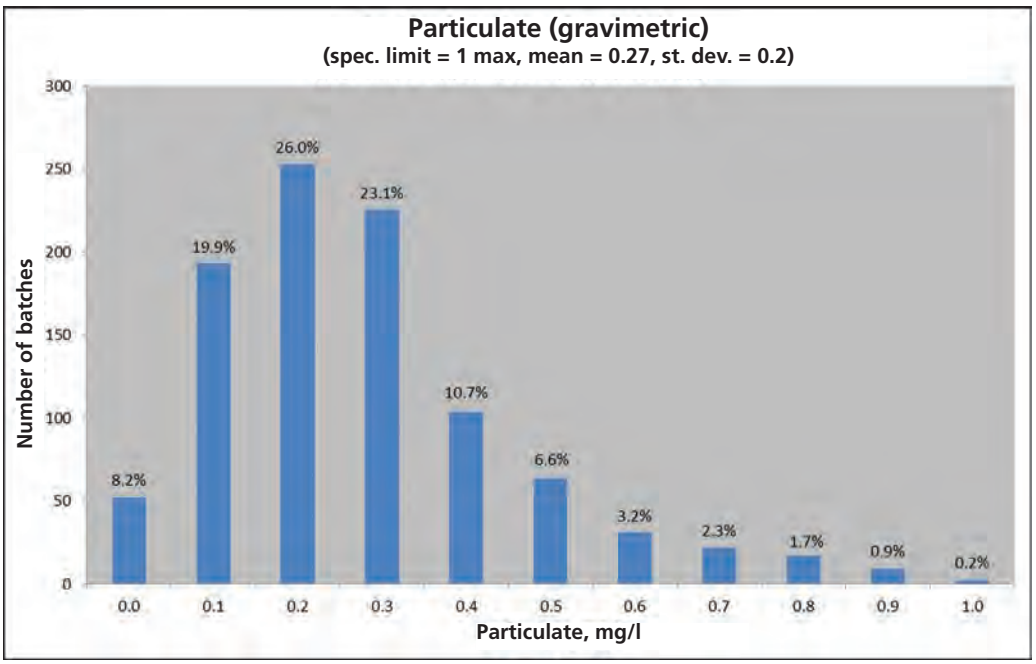

Figure 112: Particulate histogram 2012

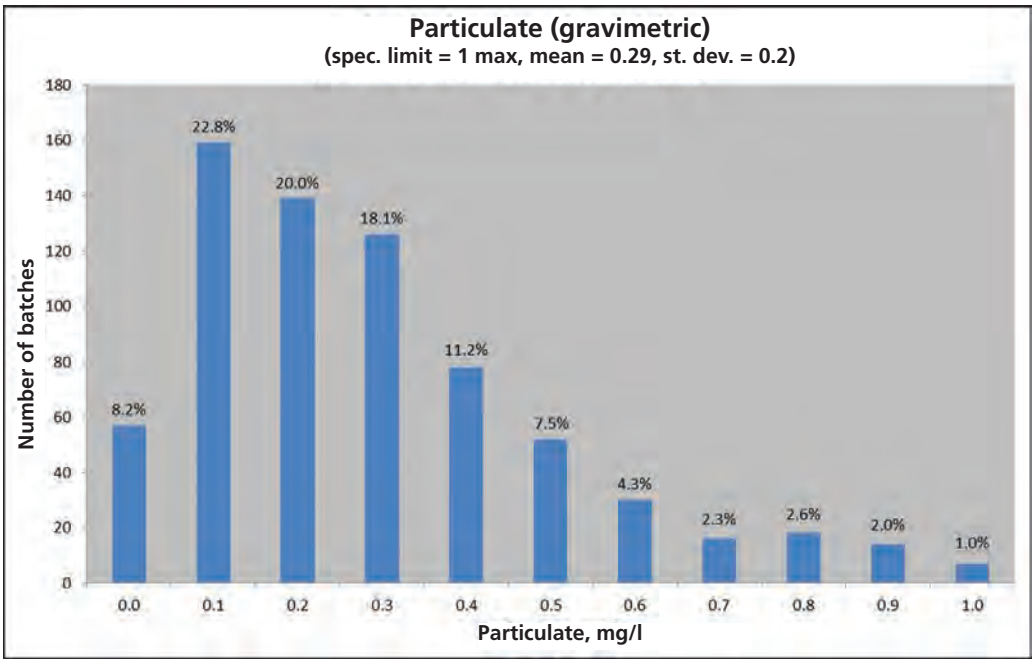

Figure 113: Particulate histogram 2013

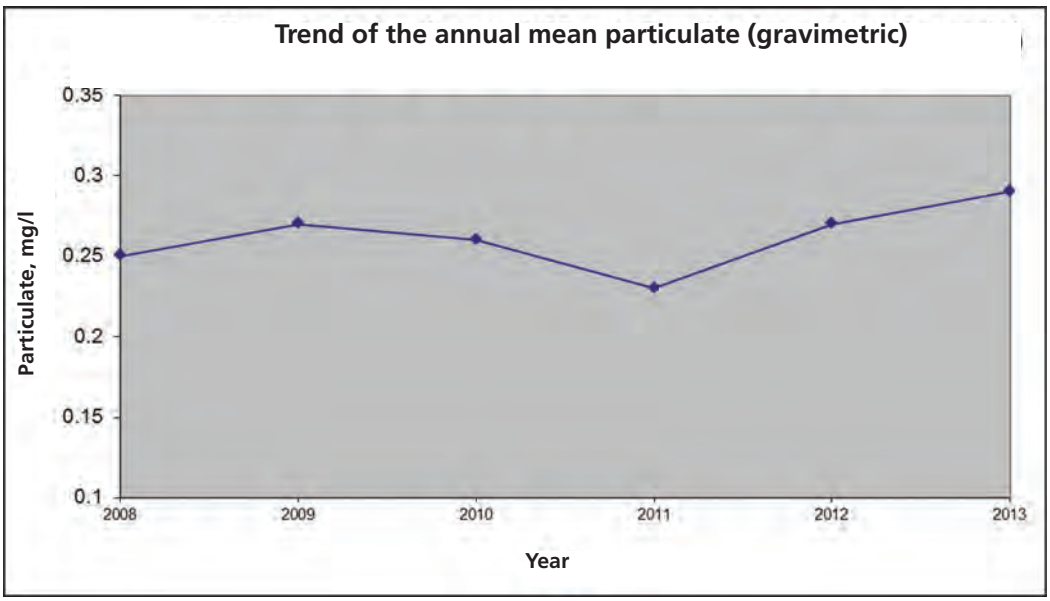

Figure 114: Particulate trend graph

B.20 SAYBOLT COLOUR

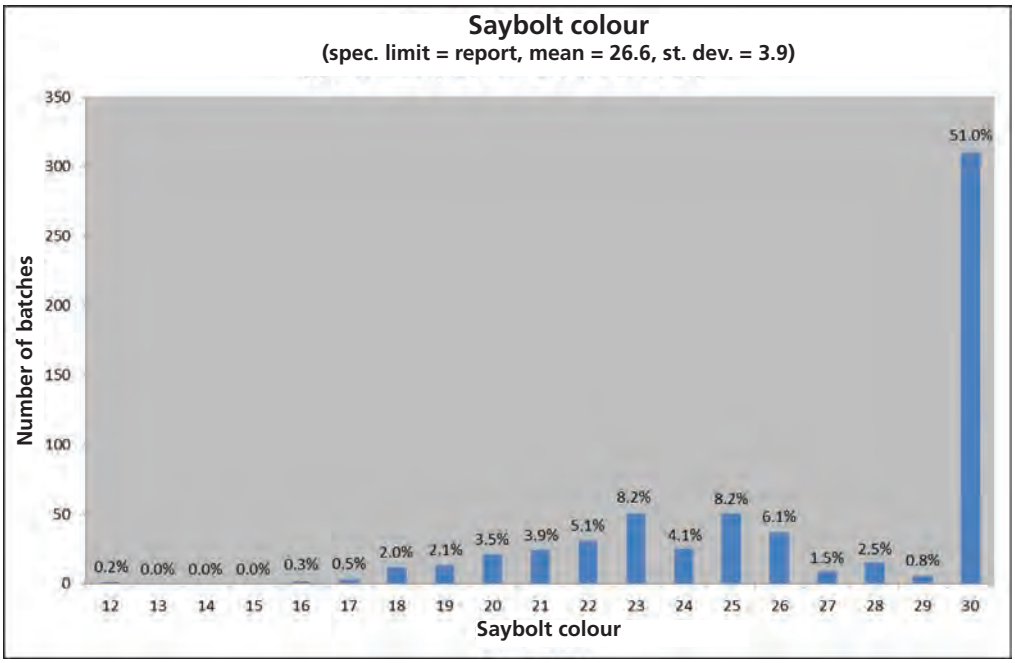

Figure 115: Saybolt colour histogram 2009

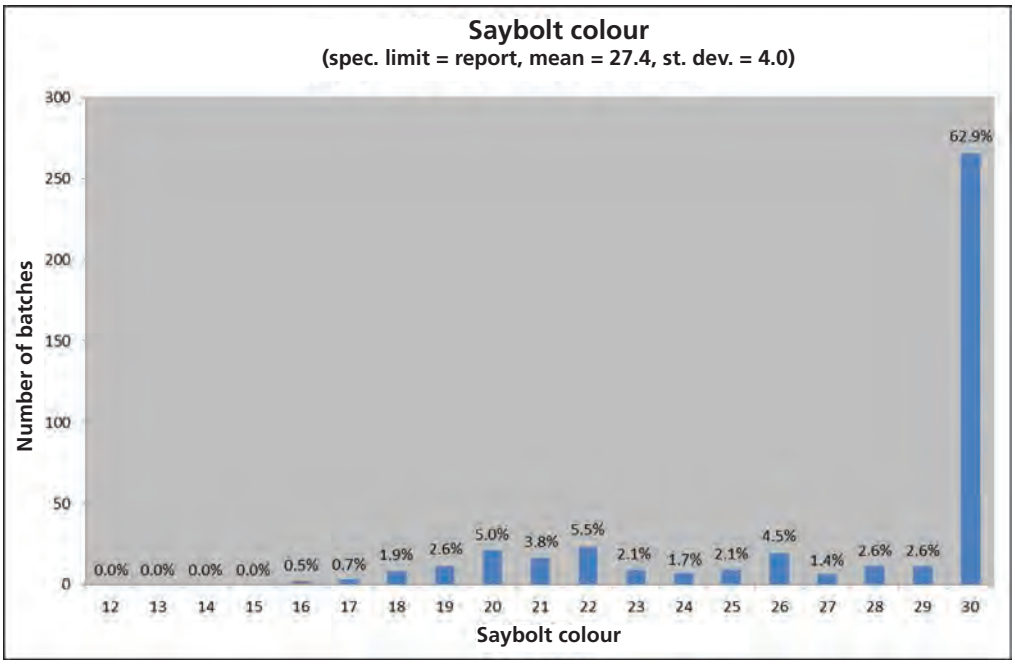

Figure 116: Saybolt colour histogram 2010

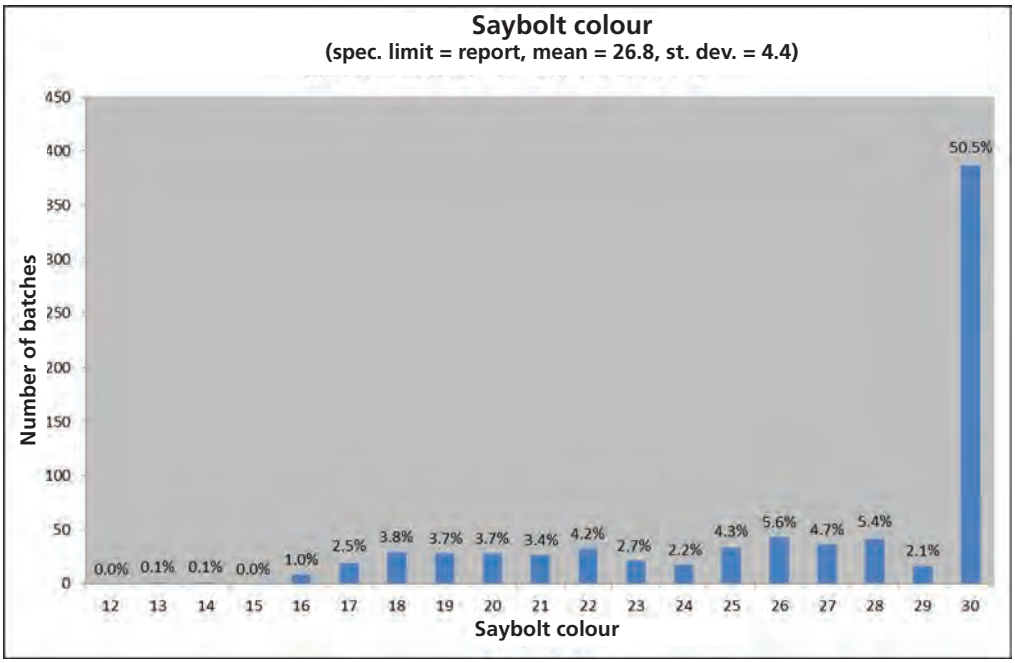

Figure 117: Saybolt colour histogram 2011

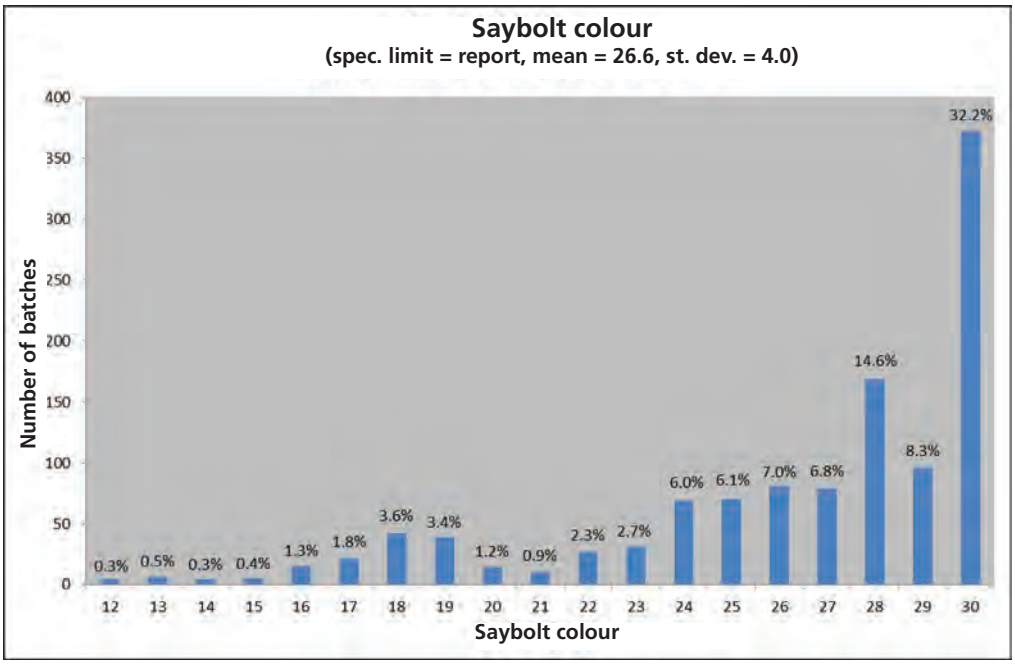

Figure 118: Saybolt colour histogram 2012

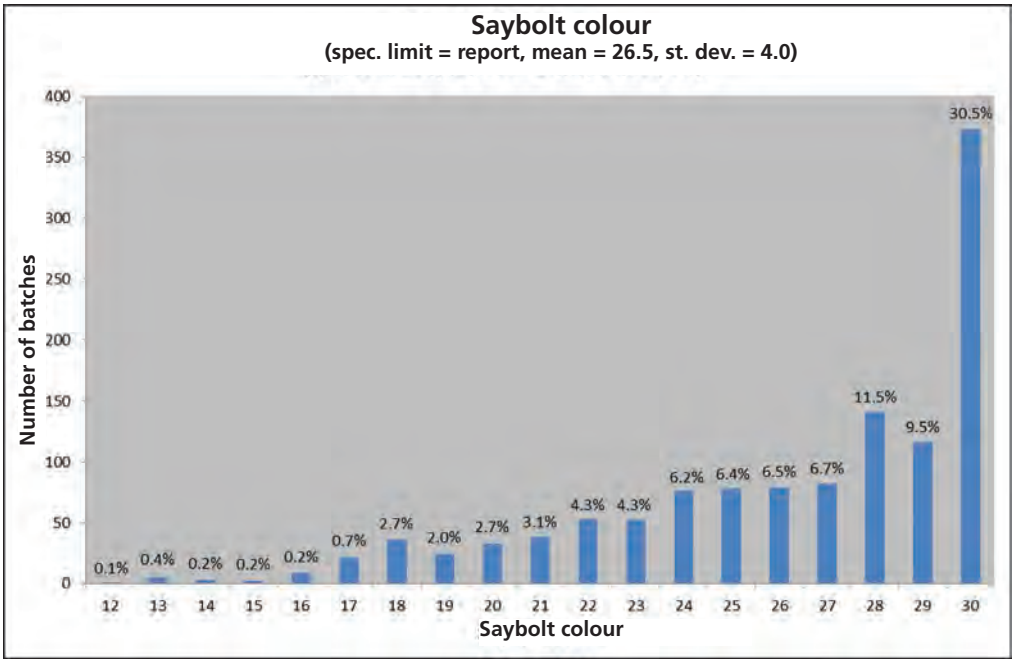

Figure 119: Saybolt colour histogram 2013

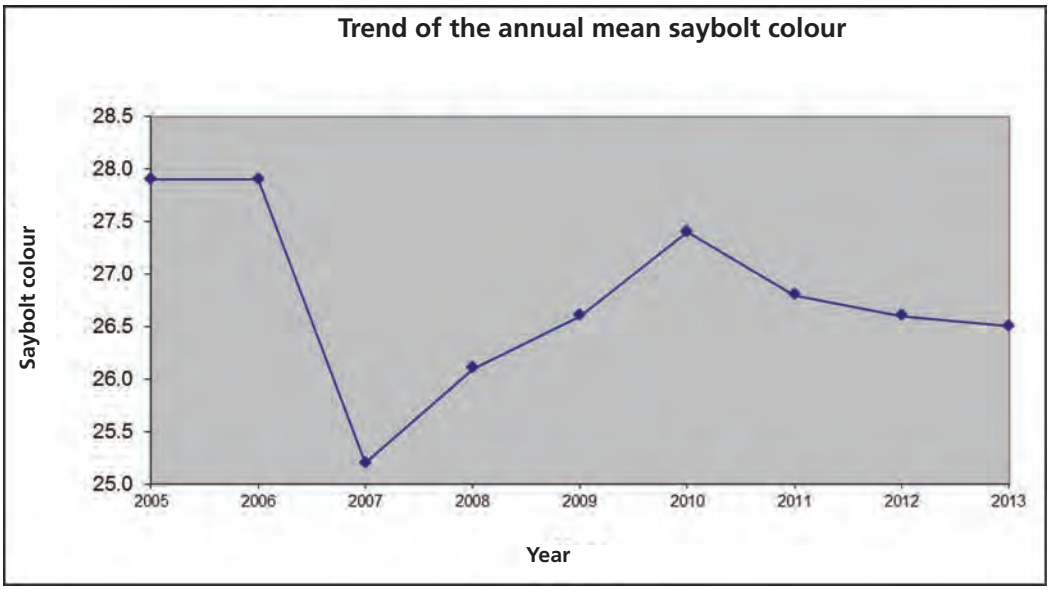

Figure 120: Saybolt colour trend graph

B.21 PARTICLE COUNTS

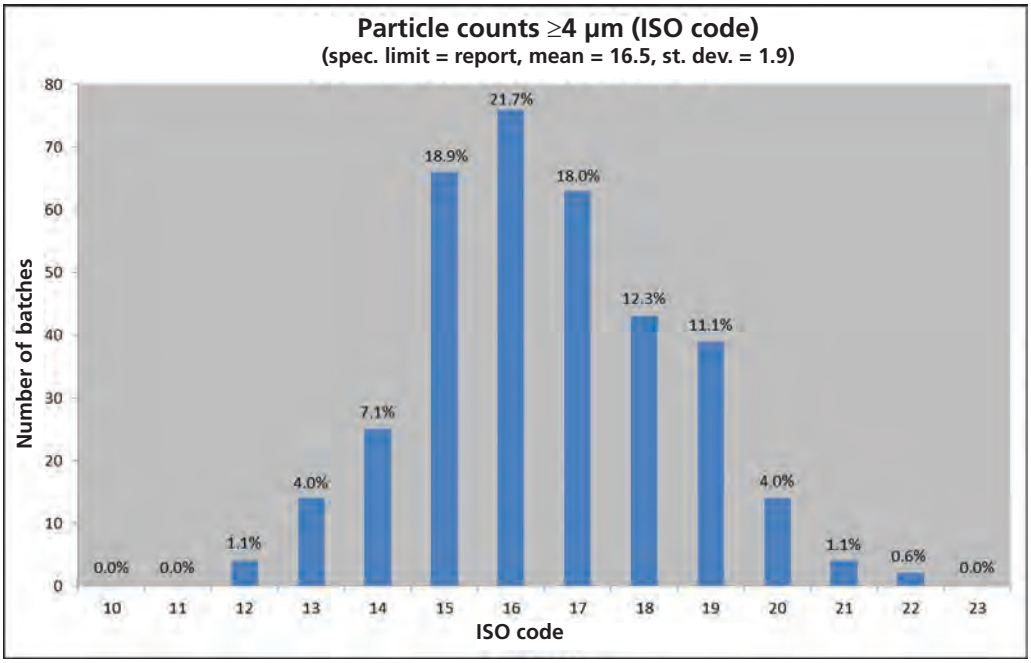

Figure 121: Particle counts ≥4 µm ISO code 2009

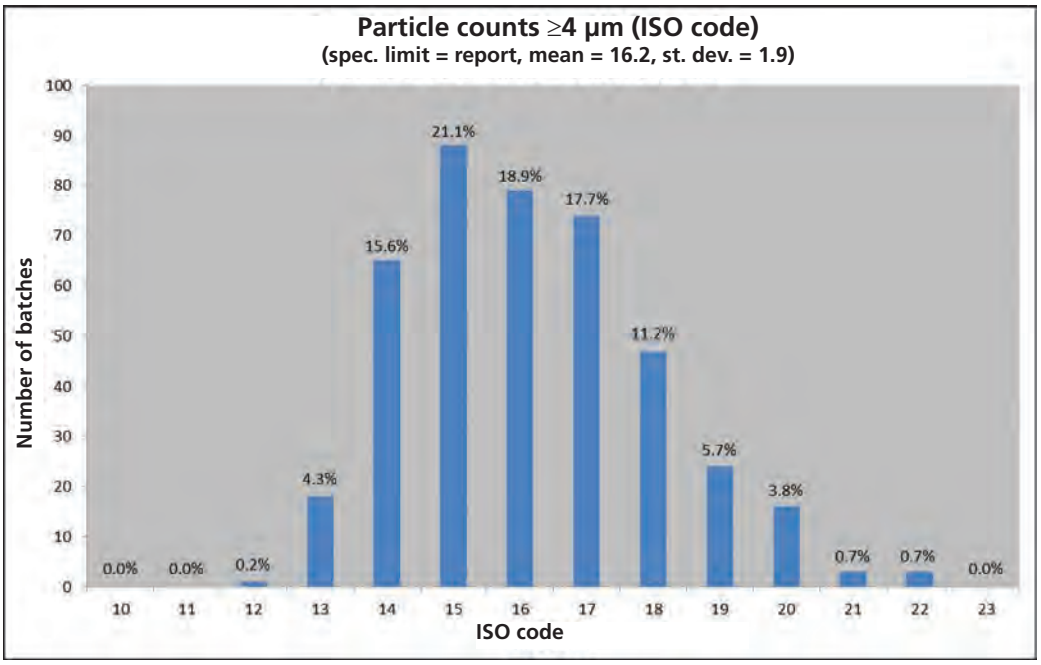

Figure 122: Particle counts ≥4 µm ISO code 2010

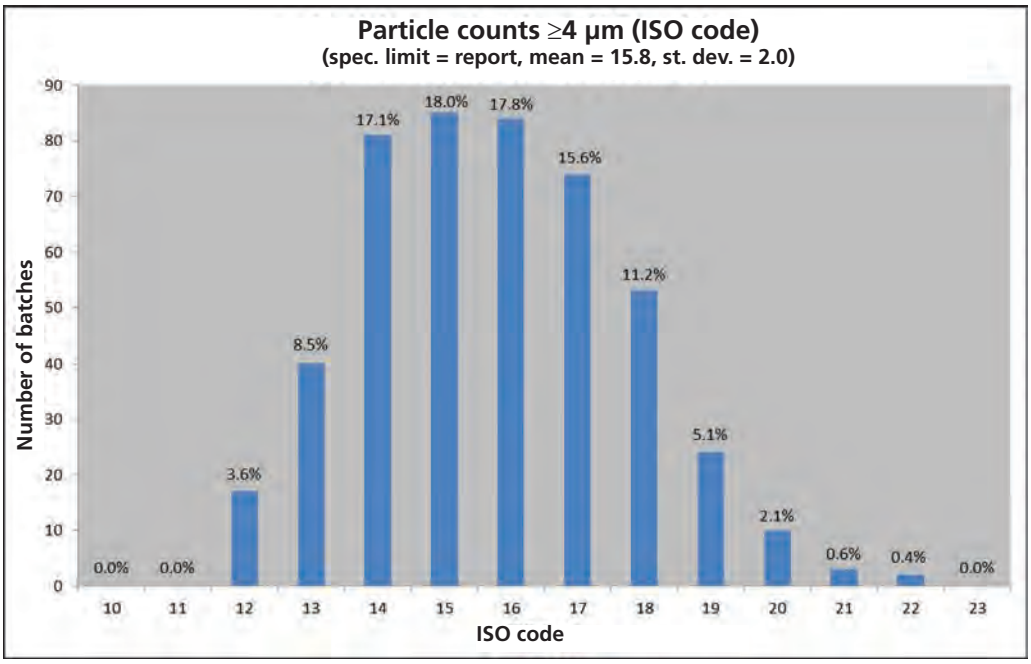

Figure 123: Particle counts ≥4 µm ISO code 2011

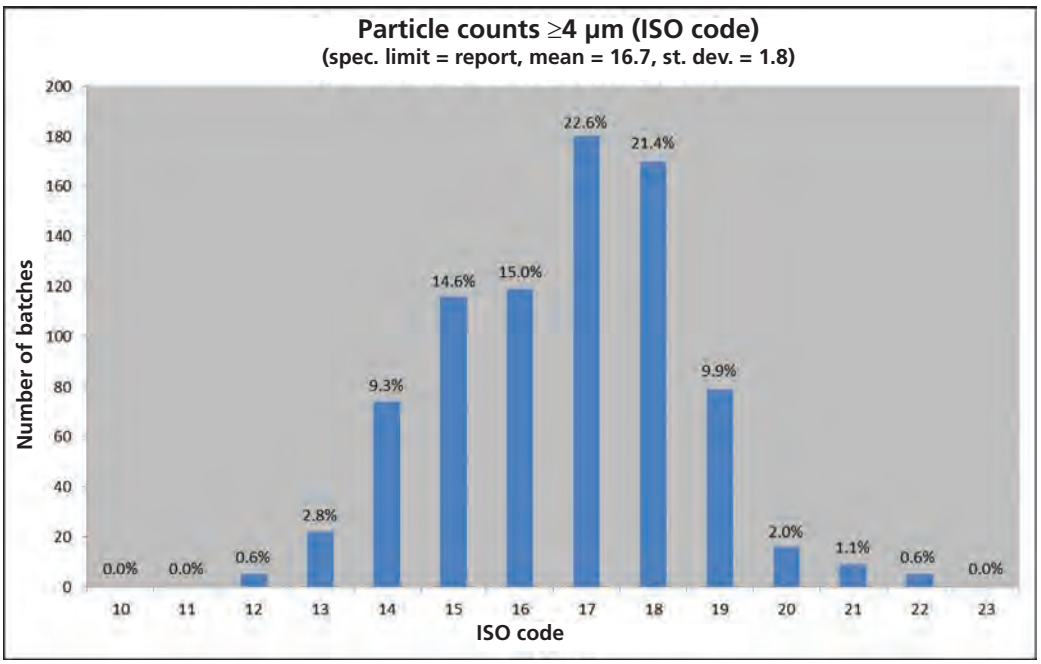

Figure 124: Particle counts ≥4 µm ISO code 2012

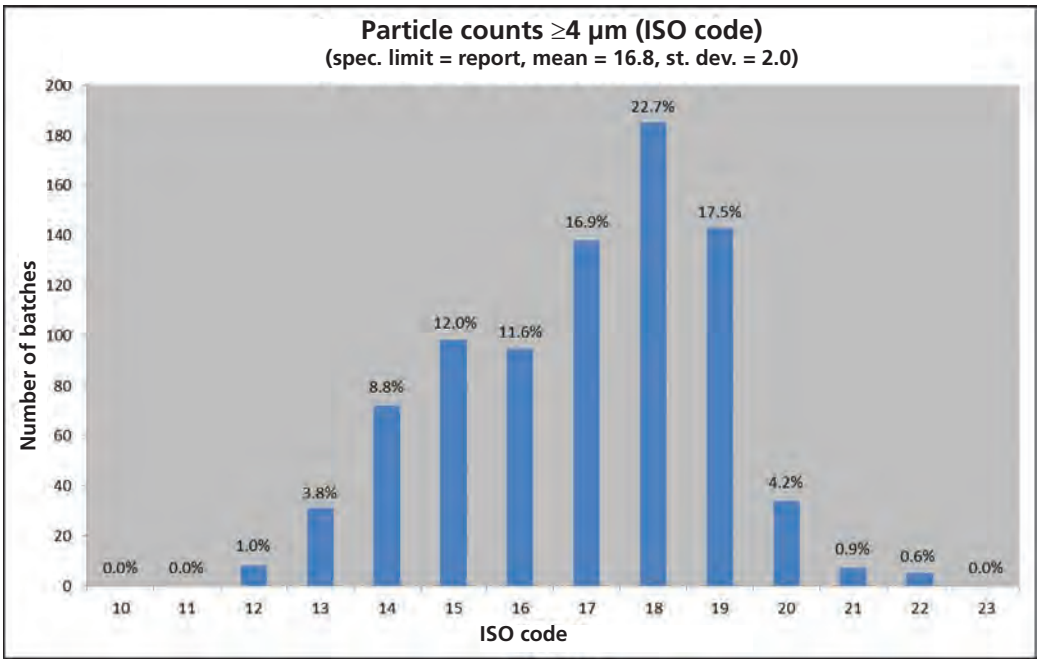

Figure 125: Particle counts ≥4 µm ISO code 2013

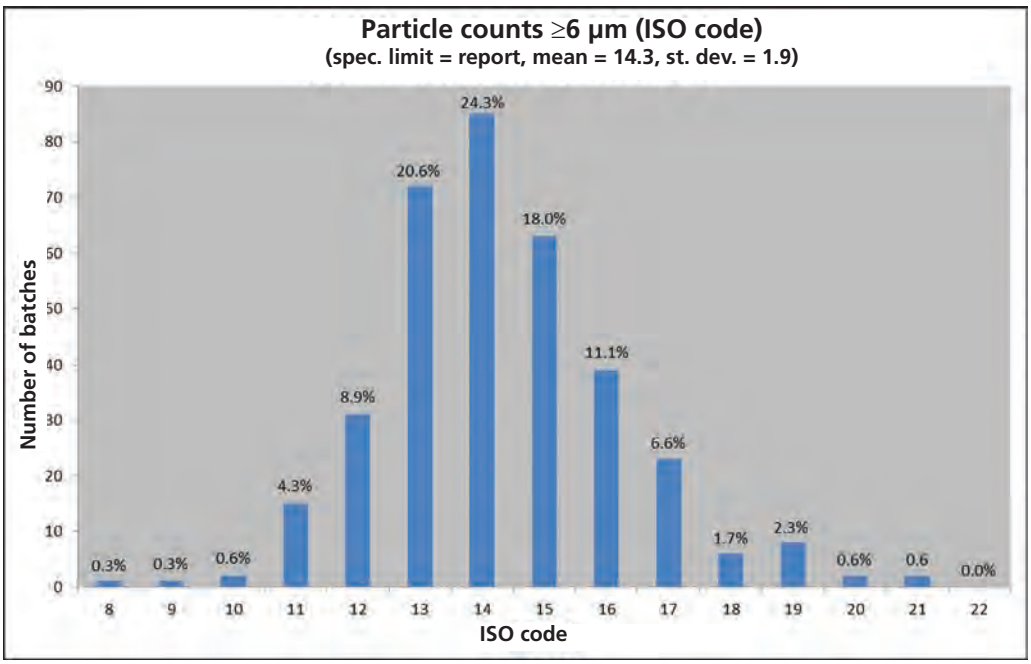

Figure 126: Particle counts ≥6 µm ISO code 2009

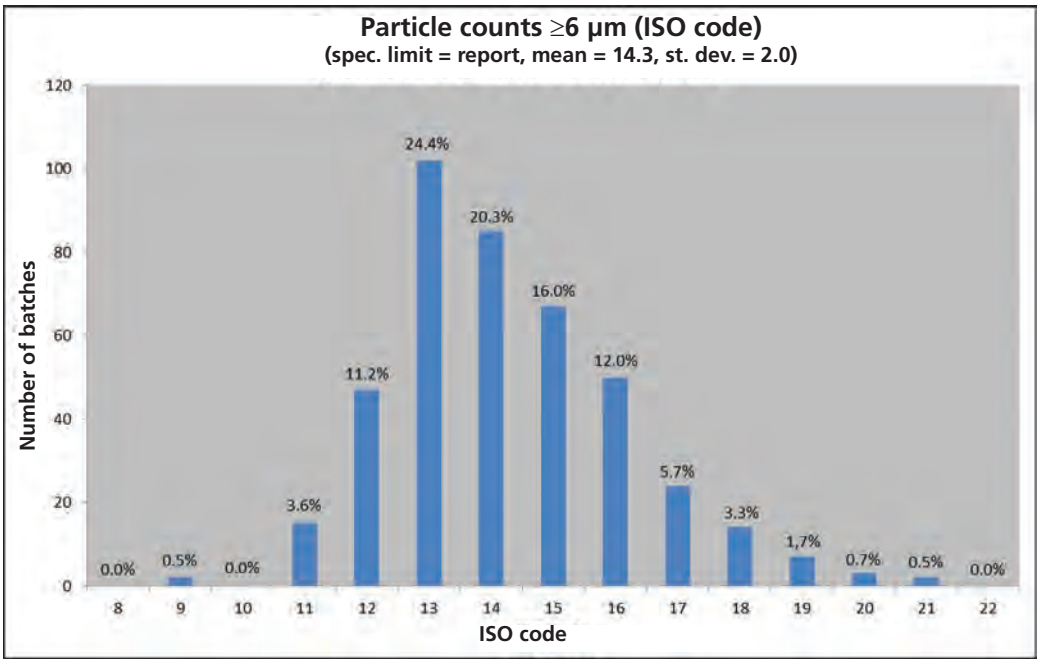

Figure 127: Particle counts ≥6 µm ISO code 2010

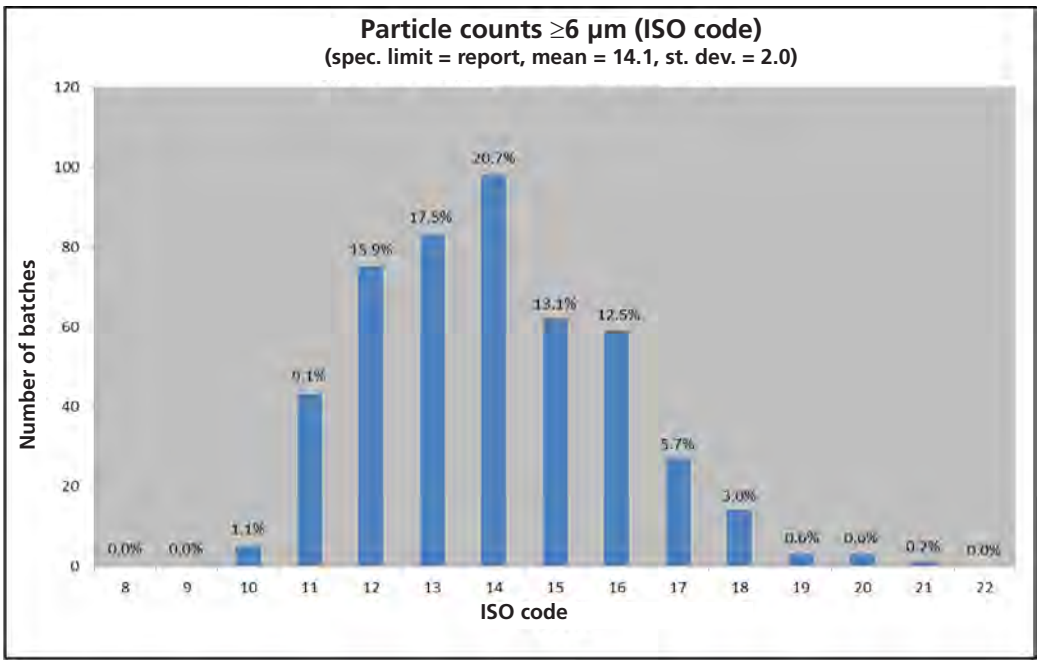

Figure 128: Particle counts ≥6 µm ISO code 2011

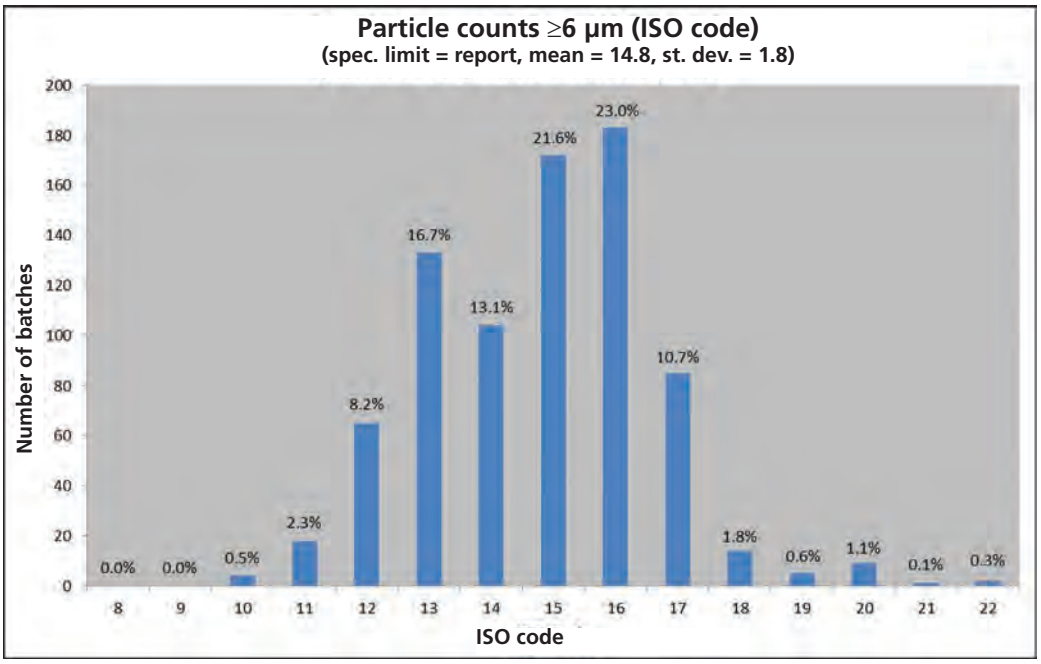

Figure 129: Particle counts ≥6 µm ISO code 2012

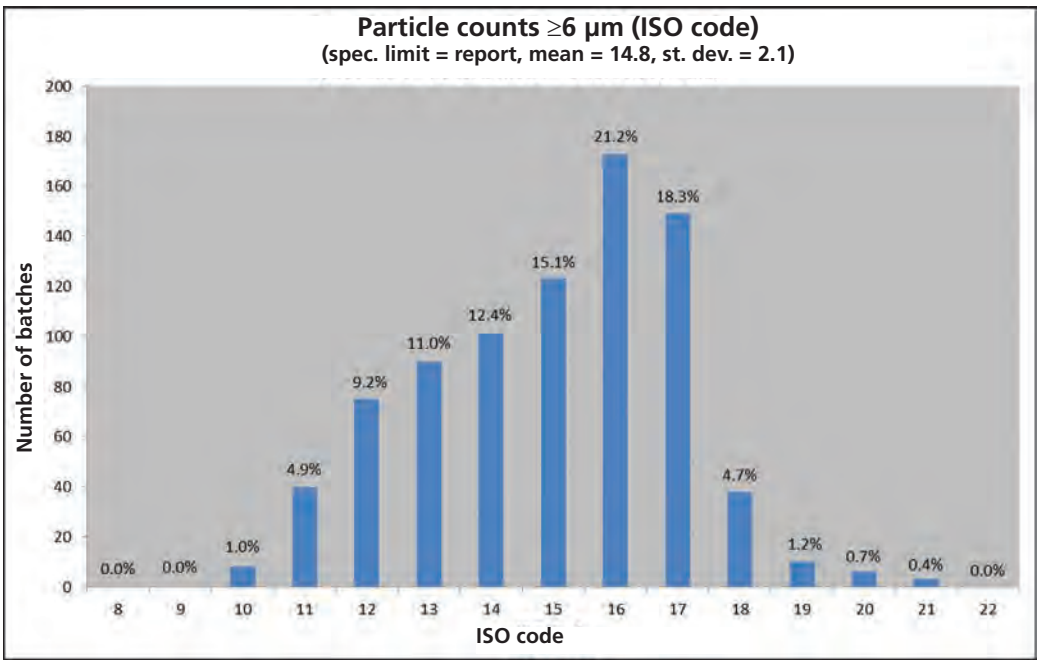

Figure 130: Particle counts ≥6 µm ISO code 2013

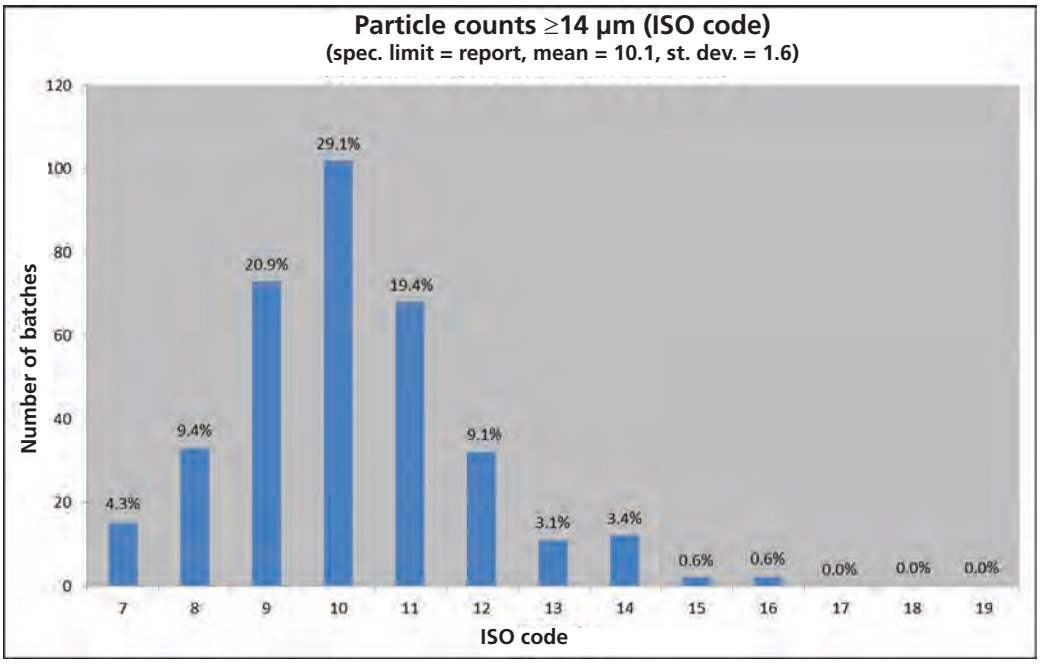

Figure 131: Particle counts ≥14 µm ISO code 2009

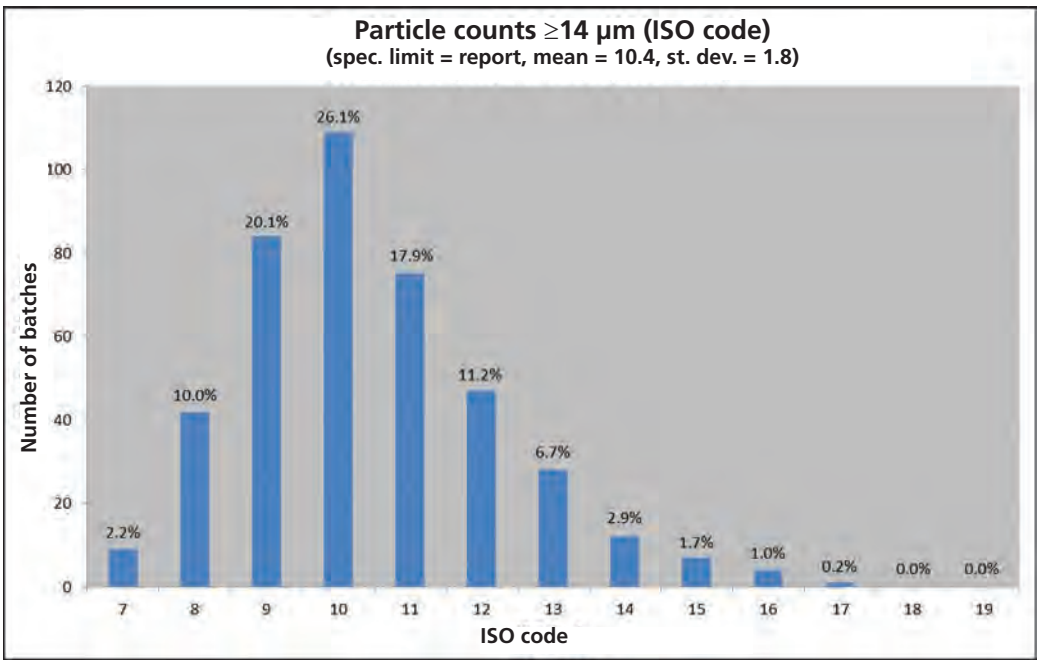

Figure 132: Particle counts ≥14 µm ISO code 2010

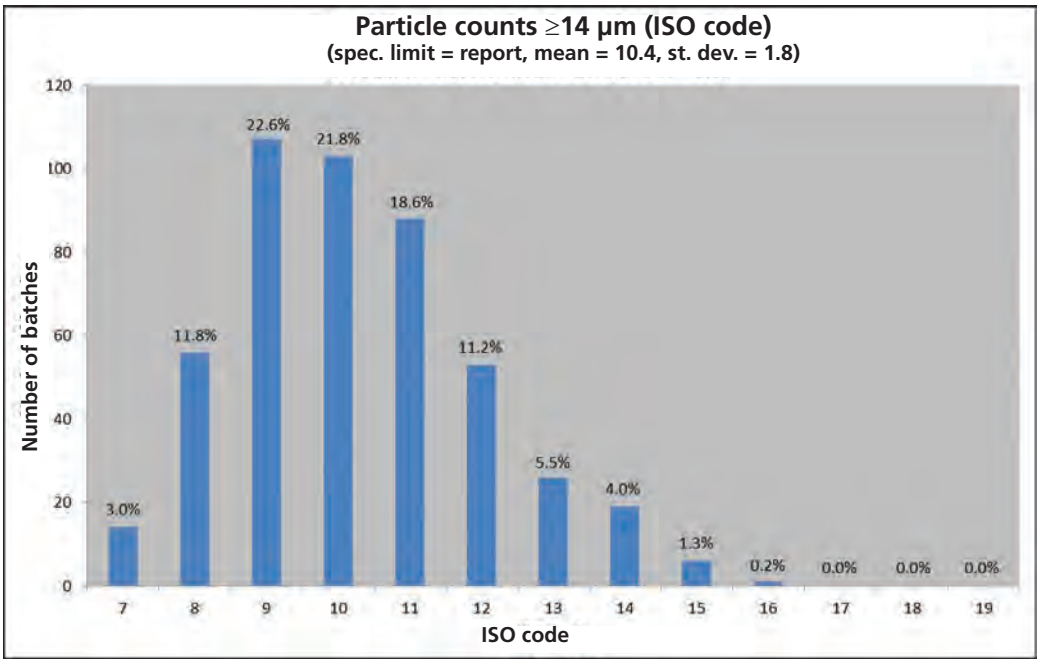

Figure 133: Particle counts ≥14 µm ISO code 2011

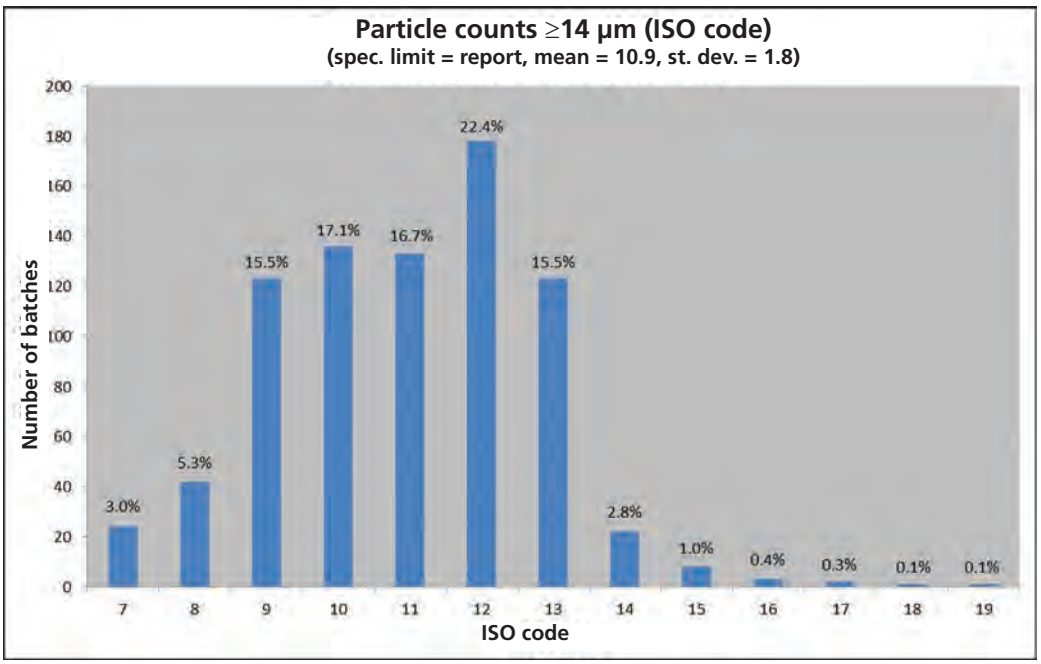

Figure 134: Particle counts ≥14 µm ISO code 2012

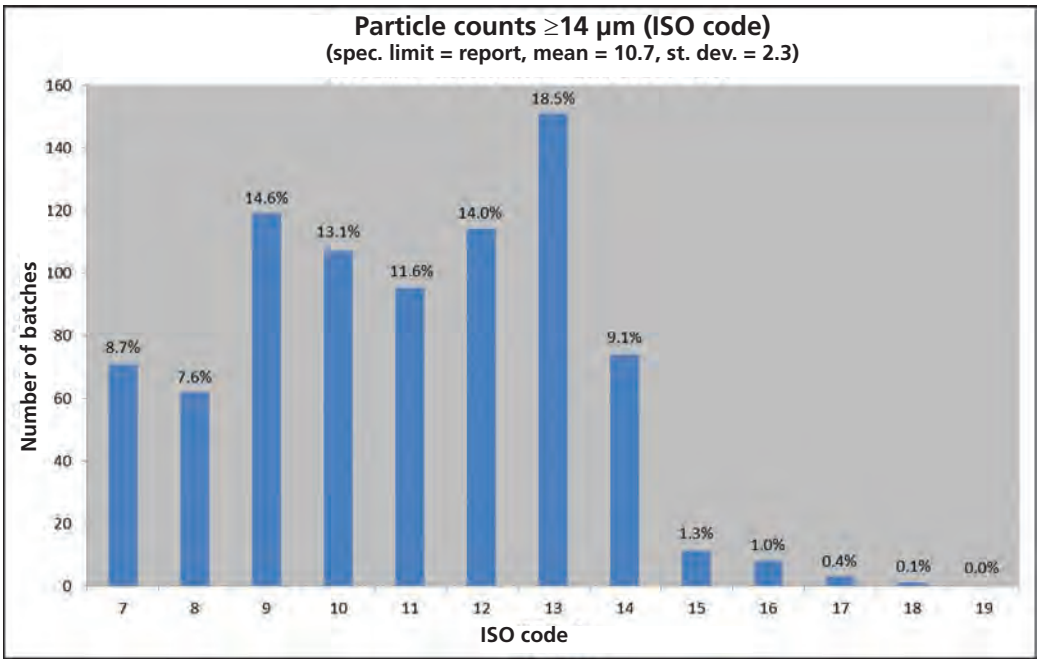

Figure 135: Particle counts ≥14 µm ISO code 2013

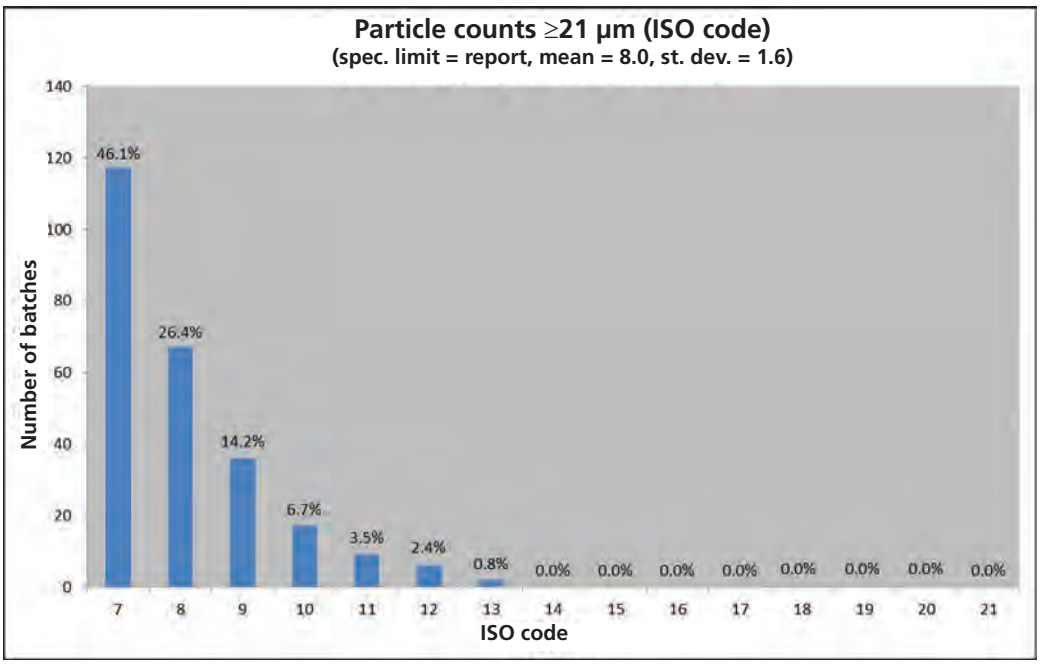

Figure 136: Particle counts ≥21 µm ISO code 2009

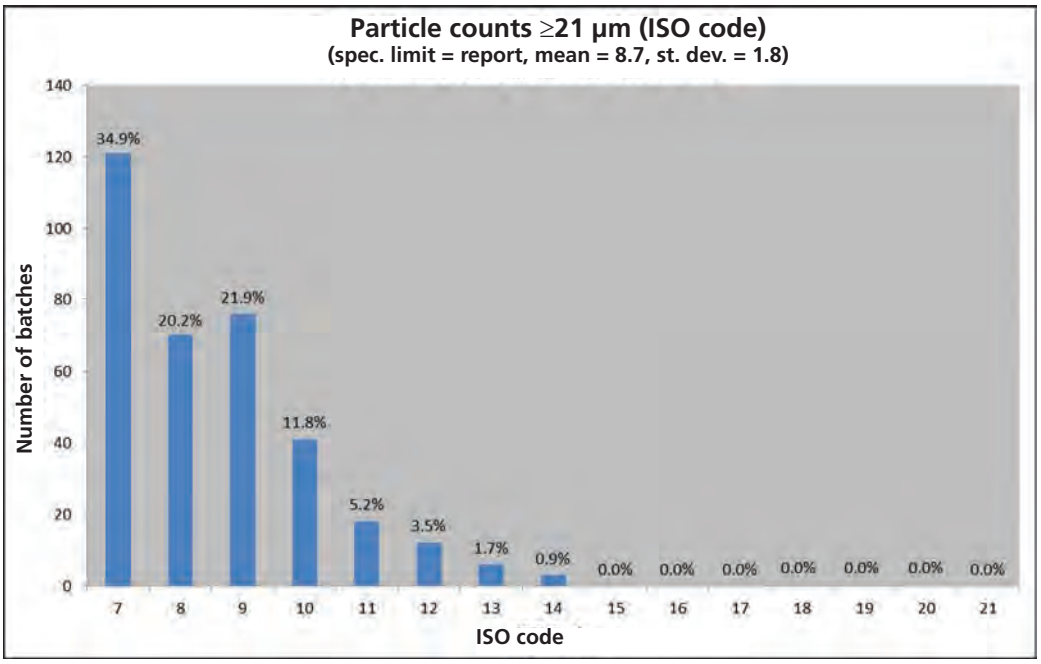

Figure 137, Particle counts ≥21 µm ISO code 2010

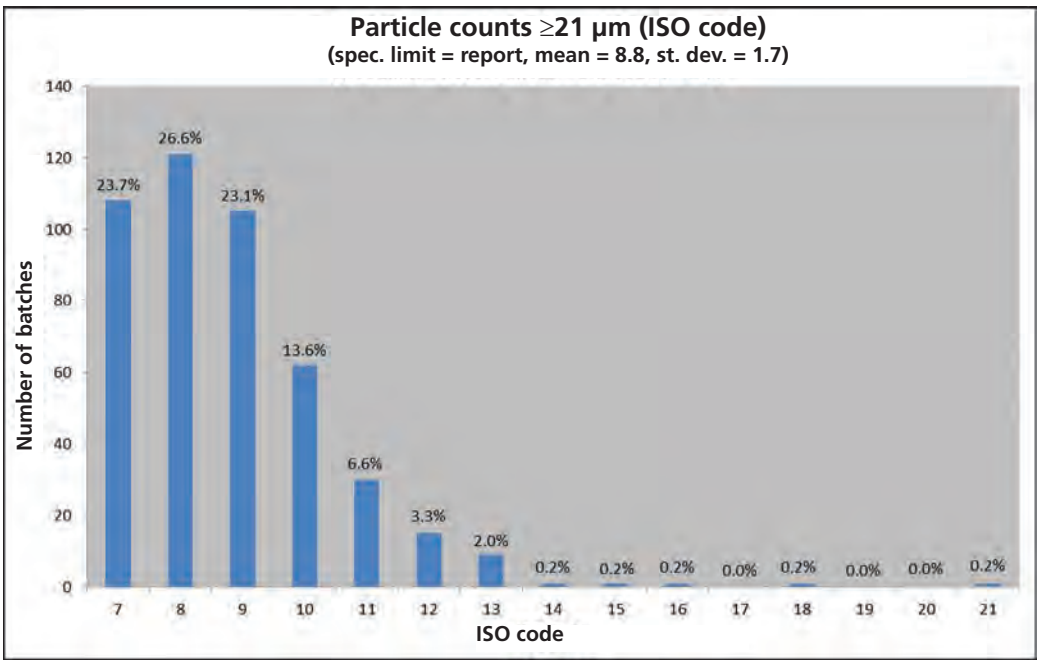

Figure 138, Particle counts ≥21 µm ISO code 2011

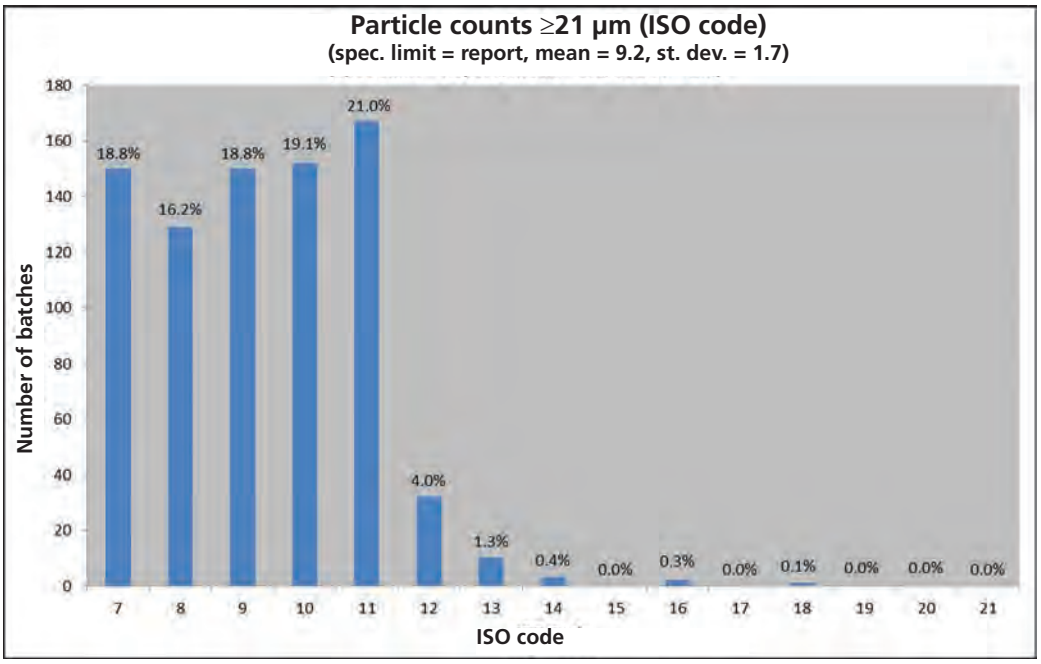

Figure 139: Particle counts ≥21 µm ISO code 2012

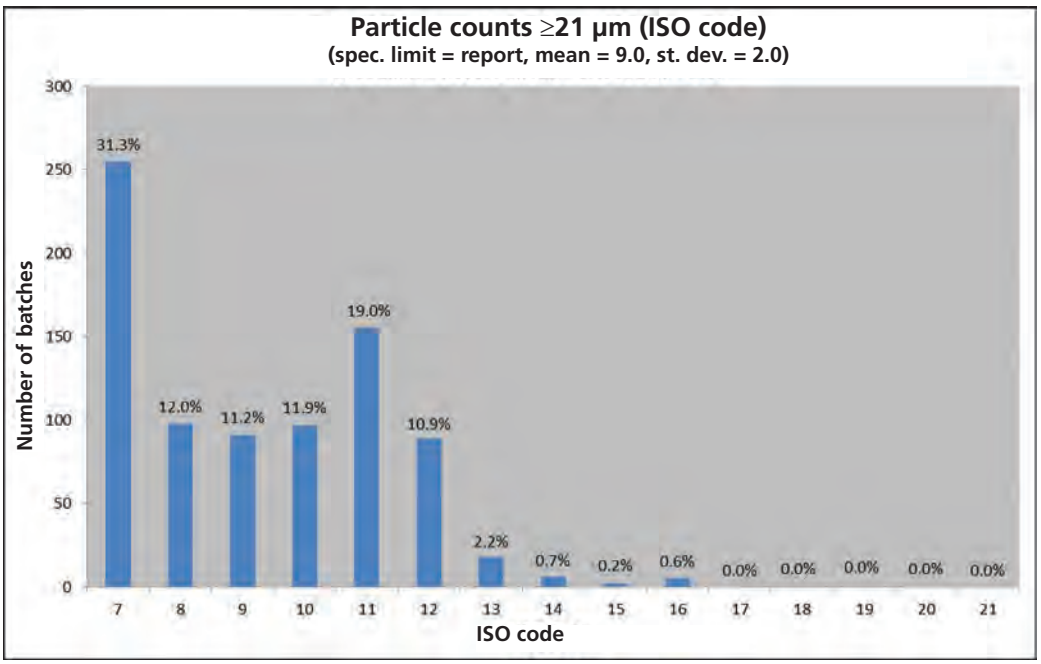

Figure 140: Particle counts ≥21 µm ISO code 2013

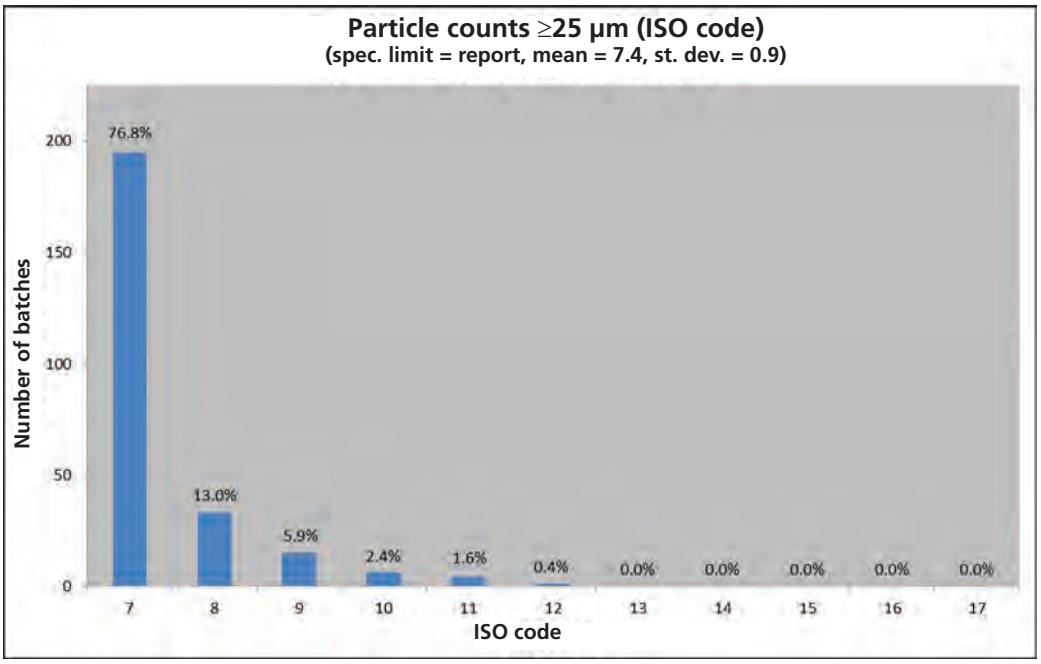

Figure 141: Particle counts ≥25 µm ISO code 2009

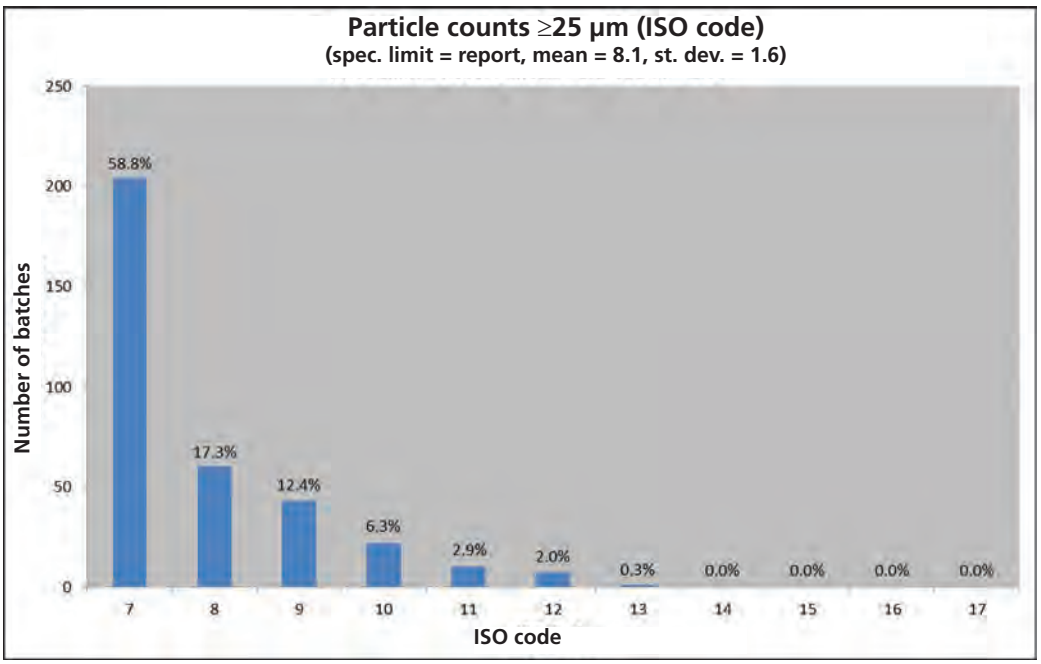

Figure 142: Particle counts ≥25 µm ISO code 2010

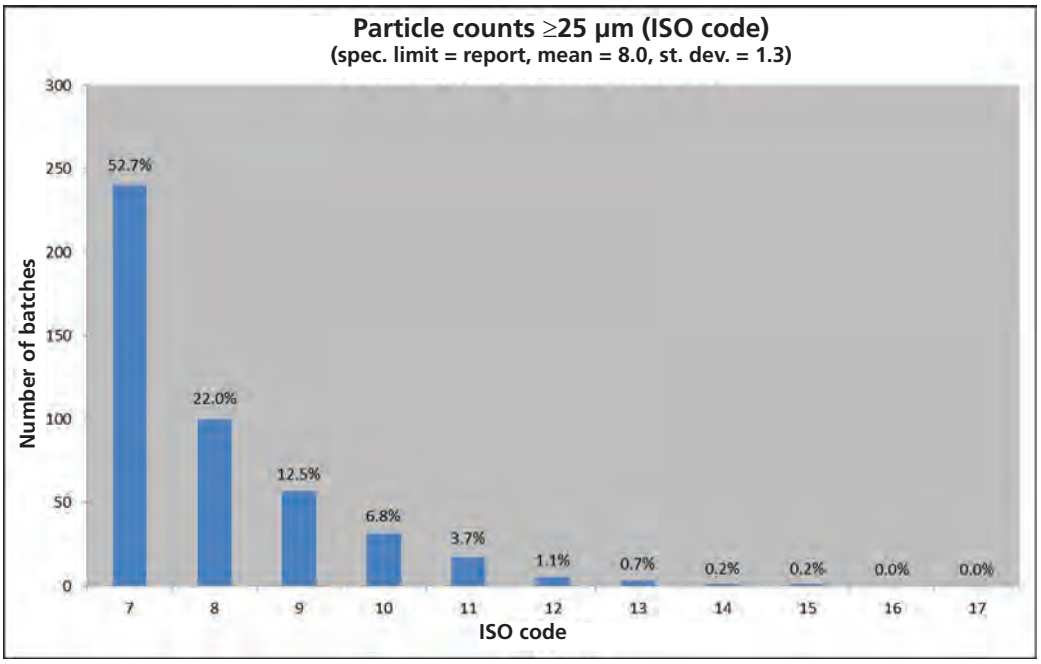

Figure 143: Particle counts ≥25 µm ISO code 2011

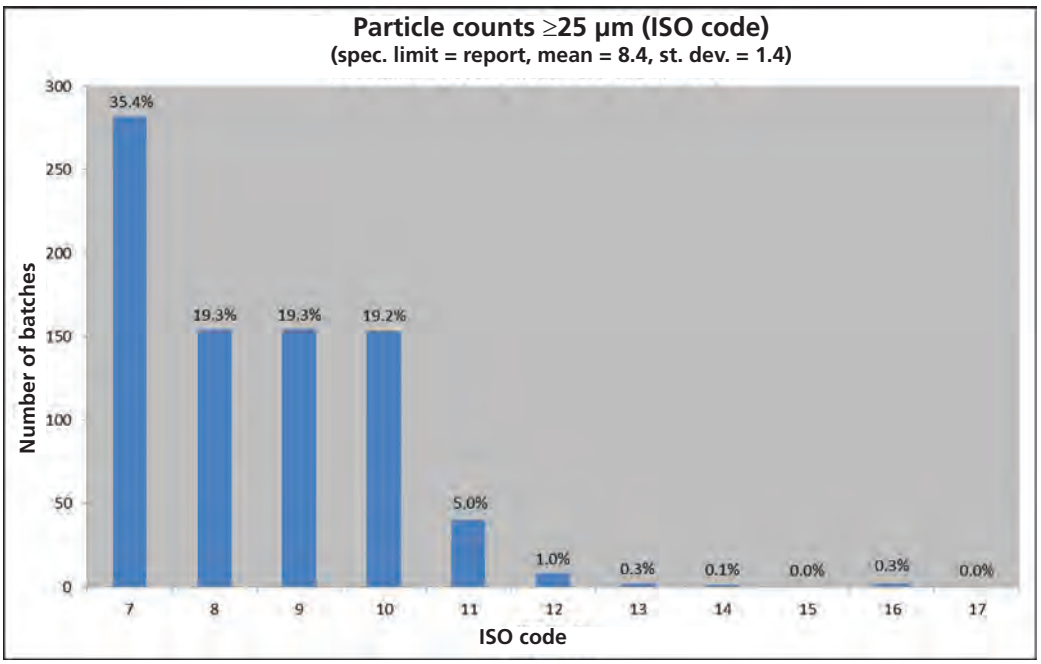

Figure 144: Particle counts ≥25 µm ISO code 2012

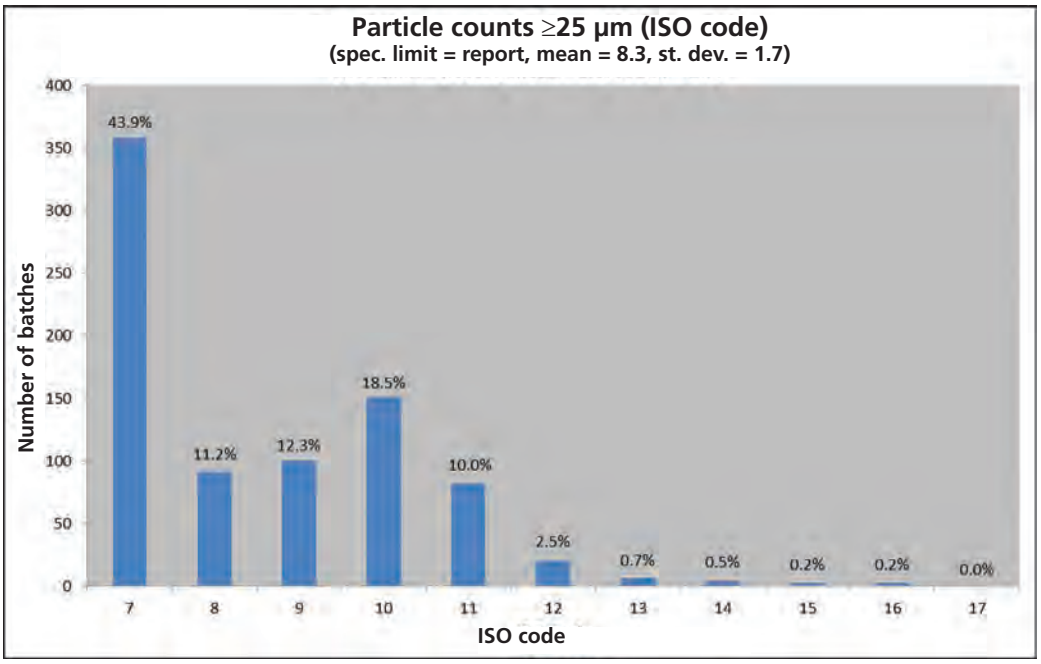

Figure 145: Particle counts ≥25 µm ISO code 2013

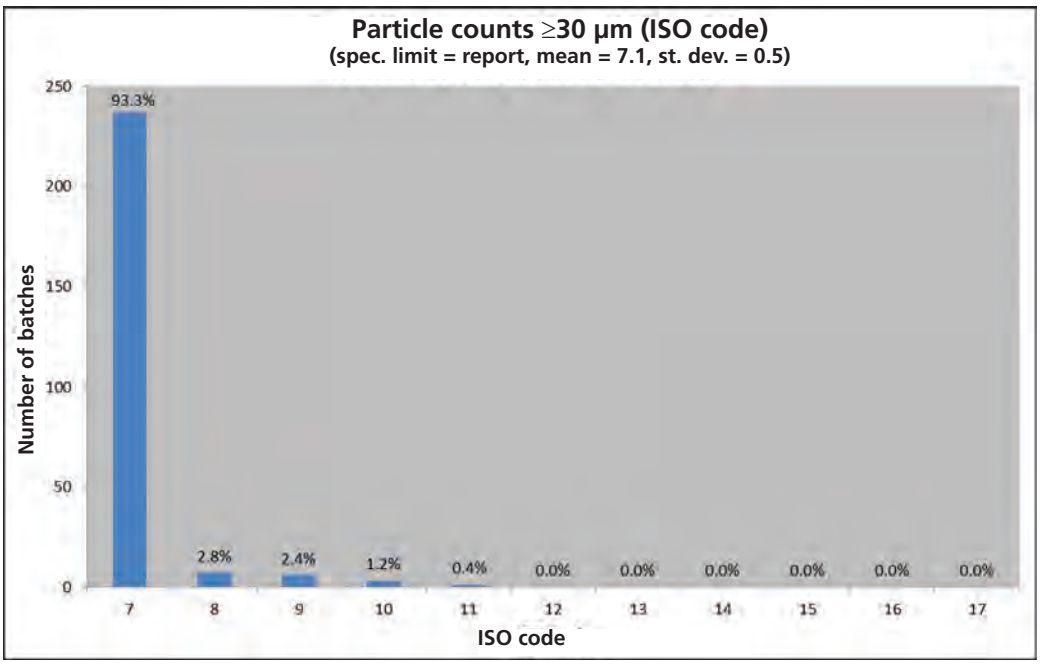

Figure 146: Particle counts ≥30 µm ISO code 2009

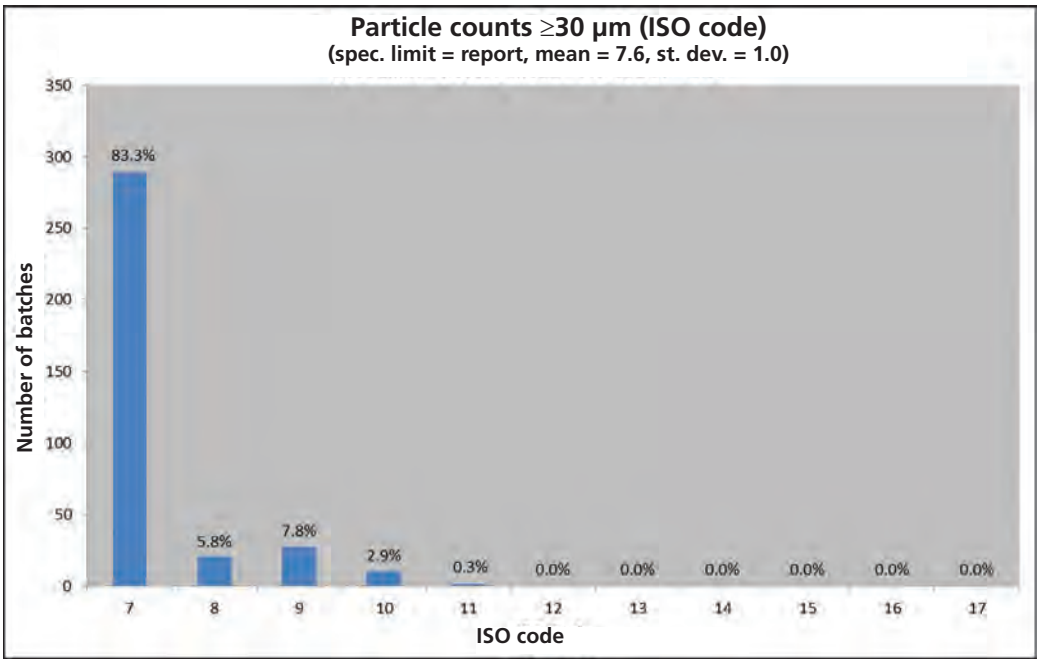

Figure 147: Particle counts ≥30 µm ISO code 2010

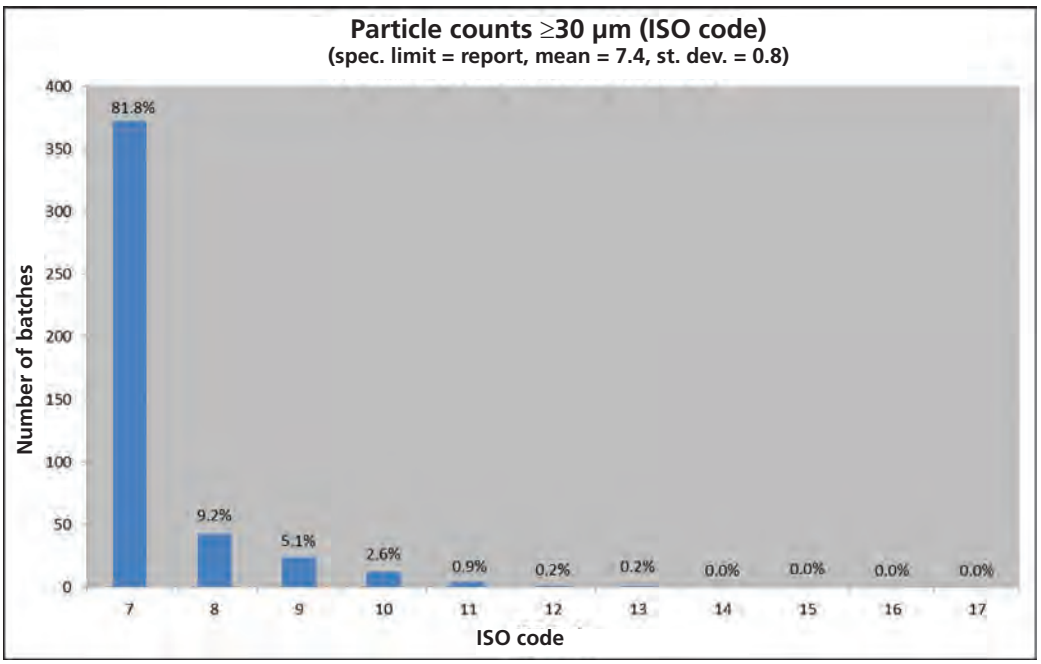

Figure 148: Particle counts ≥30 µm ISO code 2011

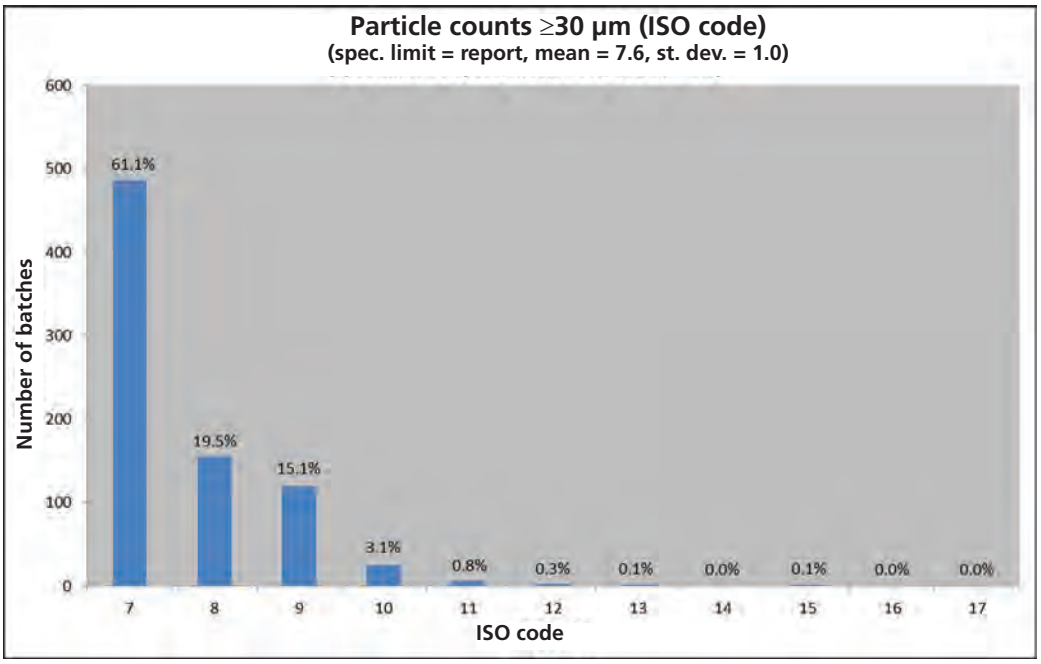

Figure 149: Particle counts ≥30 µm ISO code 2012

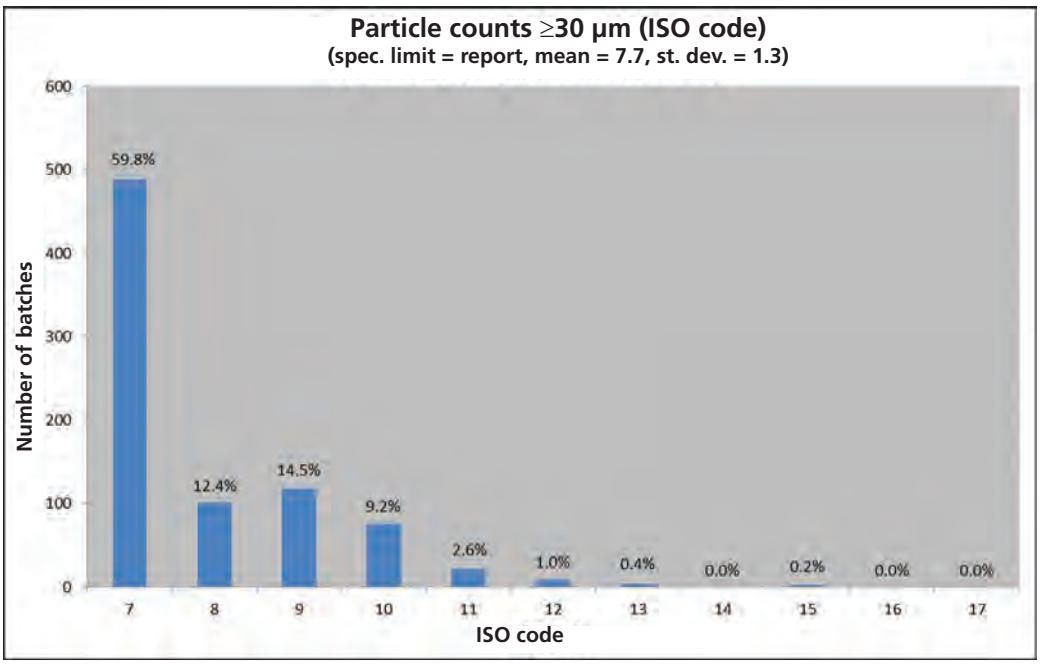

Figure 150: Particle counts ≥30 µm ISO code 2013

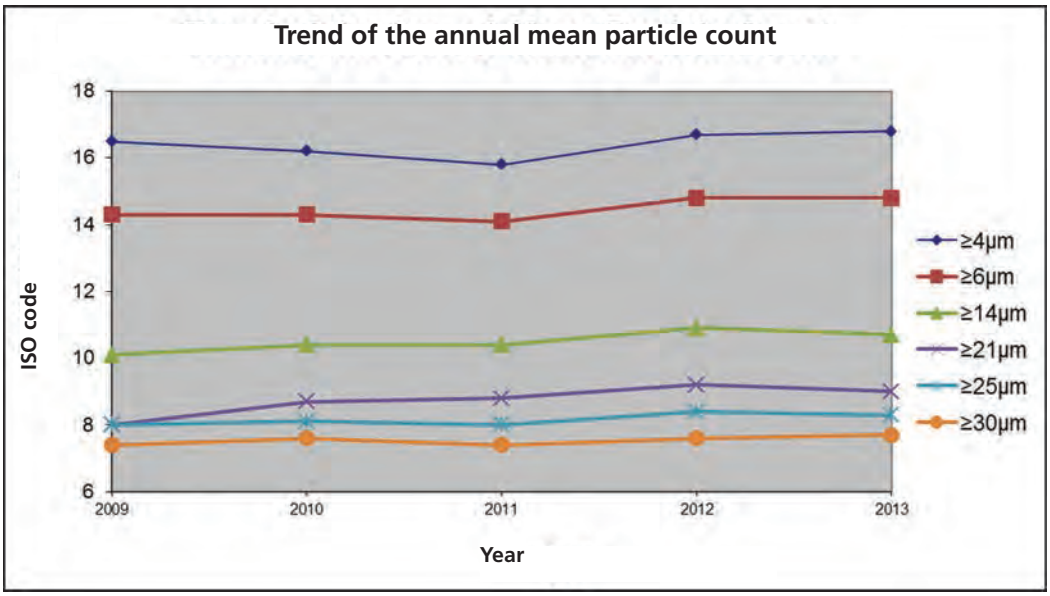

Figure 151: Particle count trend graph

B.22 NEAR SPECIFICATION LIMIT TREND ANALYSIS

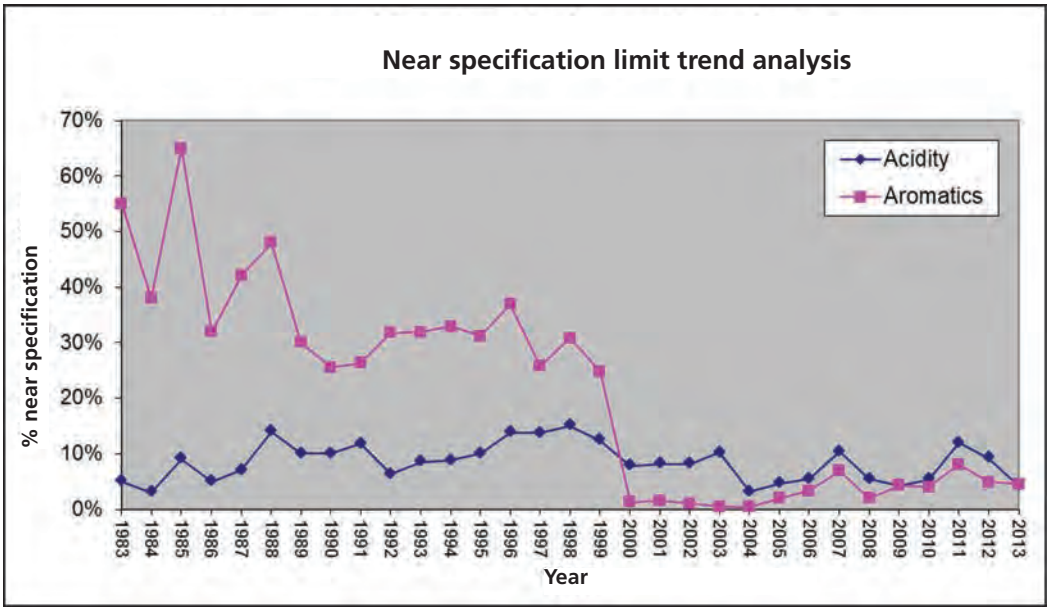

Figure 152: Near specification trend, acidity and aromatics

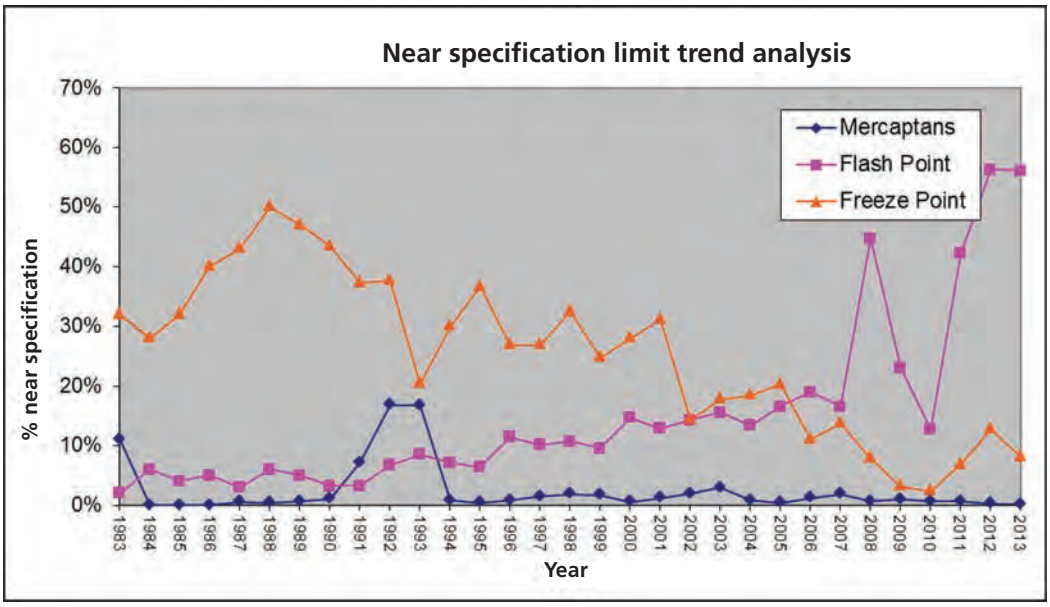

Figure 153: Near specification trend, mercaptans, flash point and freezing point

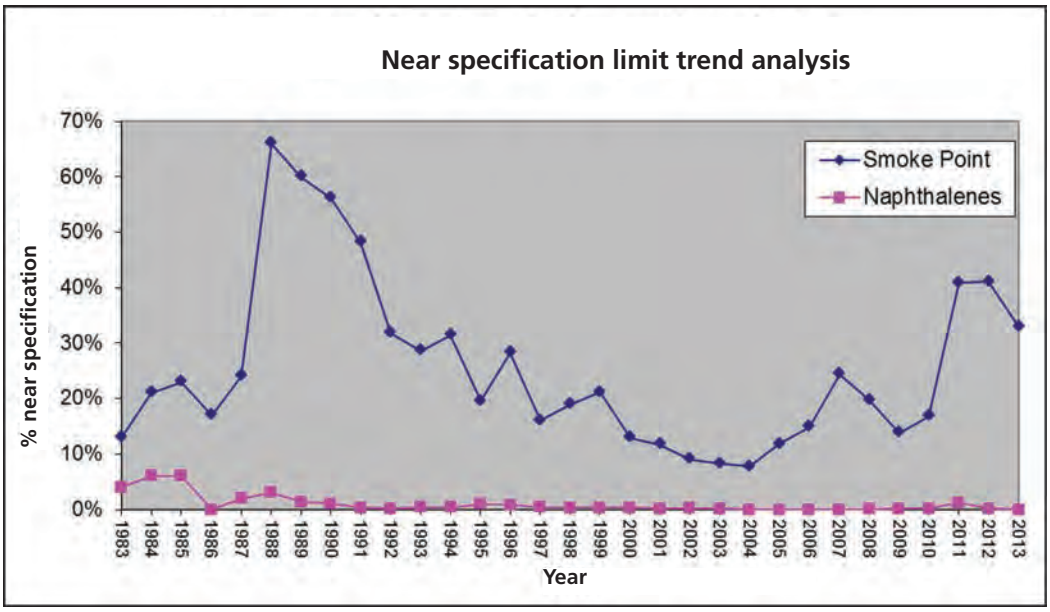

Figure 154: Near specification trend, smoke point and naphthalenes

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