Assessment of BQ-9000 Biodiesel Properties for 2024

Robert L. McCormick

National Renewable Energy Laboratory

Produced under direction of Clean Fuels Alliance America by NREL under Cooperative Research and Development Agreement CRD-23-24281.

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The author extends special thanks to Dr. Richard Nelson of Enersol Resources, Mr. Scott Fenwick of Clean Fuels Alliance America, and Mr. Steve Howell of MARC-IV Consulting, Inc. for technical support.

List of Acronyms

ASTM	ASTM International
CSFT	cold soak filterability test
NREL	National Renewable Energy Laboratory

Executive Summary

This is the eighth in a series of reports documenting the quality of biodiesel from U.S.- and Canadian-based producers that participate in the BQ-9000 program, the biodiesel industry's voluntary quality assurance program. Participants provided monthly data on critical quality parameters and other parameters that are part of the ASTM D6751 specifications for calendar year 2024. The quality data was provided to a team of experts, who removed any identifying company information and provided anonymized data to the National Renewable Energy Laboratory (NREL) for statistical analysis. Similar to 2023, data on kinematic viscosity, sulfated ash, distillation temperature, carbon residue, and cetane were collected, as well as individual levels of sodium, potassium, calcium, and magnesium. Critical quality parameters analyzed are listed in Table ES-1 with descriptive statistics.

Table ES-1. BQ-9000 Critical Parameter Summary, Calendar Year 2024

	# of Values Reported	Minimum	Maximum	Average	Median	Standard Deviation	95th percentile
Na, ppm	319	0	2.6	0.251	0.089	0.439	1.00
K, ppm	320	0	2.6	0.249	0.064	0.443	1.00
Ca, ppm	319	0	1.9	0.196	0.059	0.399	1.00
Mg, ppm	319	0	1.9	0.186	0.050	0.398	1.00
Na+K, ppm	355	0	5.2	0.449	0.152	0.824	2.0
Ca+Mg, ppm	355	0	3.8	0.343	0.100	0.763	2.0
Na+K+Ca+Mg, ppm	378	0	7.6	0.789	0.273	1.463	3.7
P, ppm	386	0	10.0	0.796	0.220	1.870	4.00
Flash point, °C	390	96	197	149	153	26.1	105
Alcohol control, % mass	194	0	0.19	0.09	0.09	0.04	0.14
Water and sediment, vol %	309	0	0.050	0.005	0.000	0.009	0.017
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Carbon Residue, % mass[a]	256	0.00	0.05	0.01	0.001	0.01	0.03
Cetane Number, value	272	45.6	64.6	50.9	50.2	3.7	59.1

a Run on the B100 sample. Note: Flash Point and Oxidation Stability are 5th percentile.

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1 Introduction

This is the eighth in a series of reports that documents the quality of biodiesel produced in the United States and Canada. Previously, the National Renewable Energy Laboratory (NREL) and Clean Fuels Alliance America collected and analyzed monthly quality data from BQ-9000 producers for calendar years 2017 to 2021 (Alleman 2020a, 2020b, 2020c, 2021, 2022) and 2022 and 2023 (McCormick 2023, 2024).[11] Producers were asked to voluntarily submit monthly fuel quality parameter data for analysis and inclusion in the report.

The purpose of this report is to document critical fuel quality parameters for biodiesel, and other parameters within the ASTM D6751 specifications, for calendar year 2024. These quality parameters are:

- Sodium
- Potassium
- Calcium
- Magnesium
- Sodium and potassium (Na + K)
- Calcium and magnesium (Ca + Mg)
- Sodium, potassium, calcium, and magnesium (Na + K + Ca + Mg)
- Phosphorus
- Flash point and alcohol control
- Water and sediment
- Cloud point
- Acid number
- Free and total glycerin
- Monoglycerides
- Sulfur
- Oxidation stability
- Cold soak filterability test (CSFT)
- Kinematic viscosity
- Sulfated Ash
- Distillation temperature, T90
- Carbon residue
- Cetane number.

[1] More detail on the BQ-9000 program is available at www.bq-9000.org.

2 Methods

Dr. Richard Nelson (Enersol Resources), Mr. Scott Fenwick (Clean Fuels Alliance America), and Mr. Steve Howell (MARC-IV Consulting, Inc.) contacted all BQ-9000 producers to request submission of monthly quality data for calendar year 2024. Upon receipt of the data, all identifying company information was removed. NREL only received numeric data for each parameter with no identifying company information.

Each company provided data “as is.” Due to the variety of ways companies collect and store these data, two types of data were received. In the first type, the submitted data included actual values that were used in the analysis. For our analysis, we calculated average, median, minimum, maximum, and either the 5th or 95th percentile for the data. For specification parameters in ASTM International’s (ASTM’s) B100 specification, ASTM D6751-23a, that have a minimum requirement like oxidation stability or flash point, we present a 5th percentile, where only 5% of the data are below the calculated value. All other parameters include a 95th percentile, where 95% of the data are below the calculated value.

In the second data type, the data were reported as “greater than” or “less than” a value. These data were not included in the statistical analysis in the body of this report because the actual values are unknown. In an effort to capture this information, those data have been summarized in the appendix. For this appendix summary, any values reported as “greater” or “less” than were assigned that value prior to providing the data to NREL. For example, if flash point was reported as >150°C, the analysis in the appendix assumes it was 150°C. No statistics were calculated for these data.

3 Results

The significance of the parameters included here are discussed in ASTM specification D6751-23a, *Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels* (ASTM 2023). All the data presented here and in the appendix are shown without limits. Under the BQ-9000 program, producers must follow specific procedures to resolve out-of-specification parameters. Any information on how a producer chose to resolve these issues is beyond the scope of this report. The binning for each parameter was selected for ease of presentation only.

3.1 Alkali and Alkaline Earth Metals

Figure 1 shows data for sodium levels (ppm) in biodiesel for calendar year 2024. The average was 0.251 the median 0.089, and the 95th percentile 1.00. Figure 2 presents data on potassium levels (ppm) in biodiesel in 2024. The average was 0.249, the median 0.064, and the 95th percentile 1.00. Figure 3 presents calcium levels (ppm) in biodiesel for 2024. The average, median, and 95th percentile were 0.196, 0.059, and 1.00, respectively. Figure 4 shows magnesium levels (ppm) for biodiesel in 2024. Average, median, and 95th percentile were 0.186, 0.05, and 1.00, respectively.

Figure 5 illustrates sodium and potassium (Na + K) for biodiesel in 2024. The average, median, and 95th percentile for Na + K were 0.449, 0.152, and 2.0 ppm, respectively. The Ca + Mg data for 2024 are shown in Figure 6, with an average of 0.343 ppm, a median of 0.10 ppm, and a 95th percentile of 2.0 ppm. Figure 7 reports the sum of all alkali and alkaline earth metals (Na + K + Ca + Mg) with an average of 0.789 ppm, a median of 0.273 ppm, and a 95th percentile of 3.7 ppm.

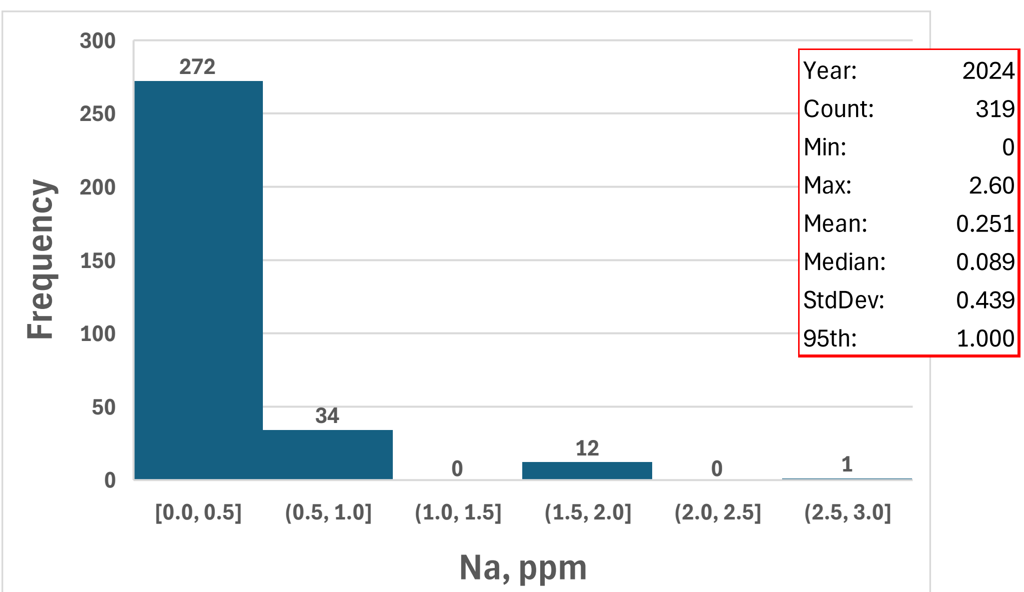

Figure 1. Sodium content of biodiesel

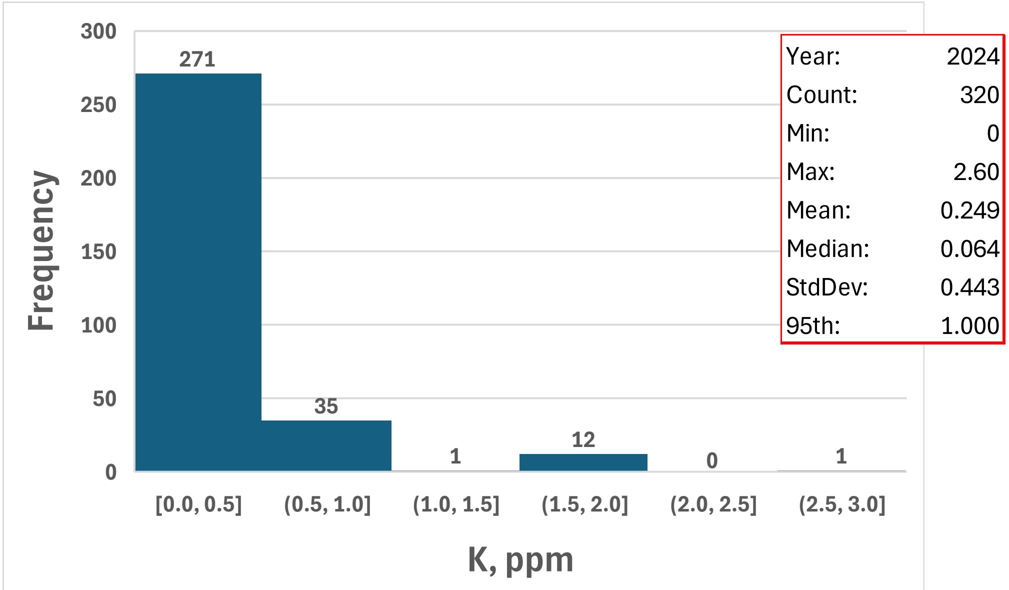

Figure 2. Potassium content of biodiesel

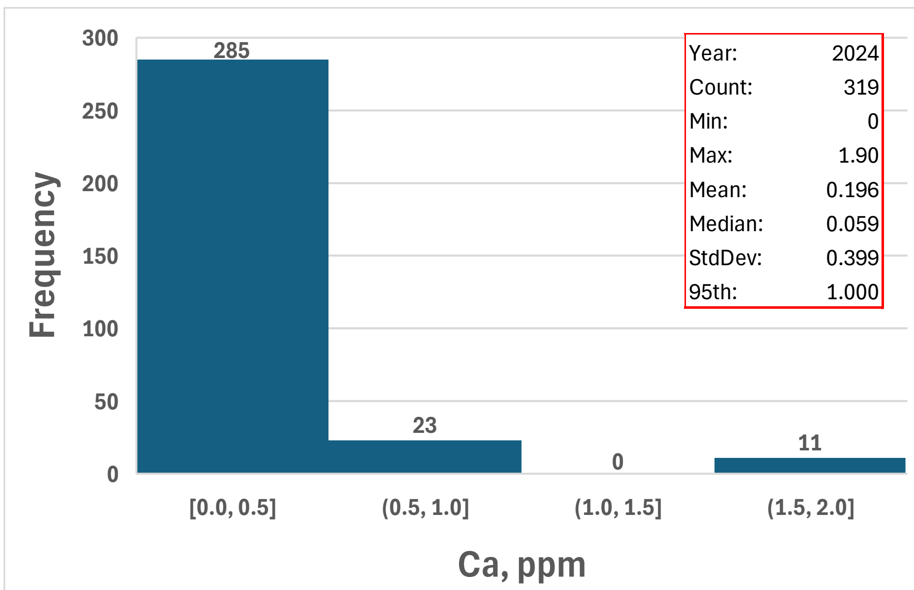

Figure 3. Calcium content of biodiesel

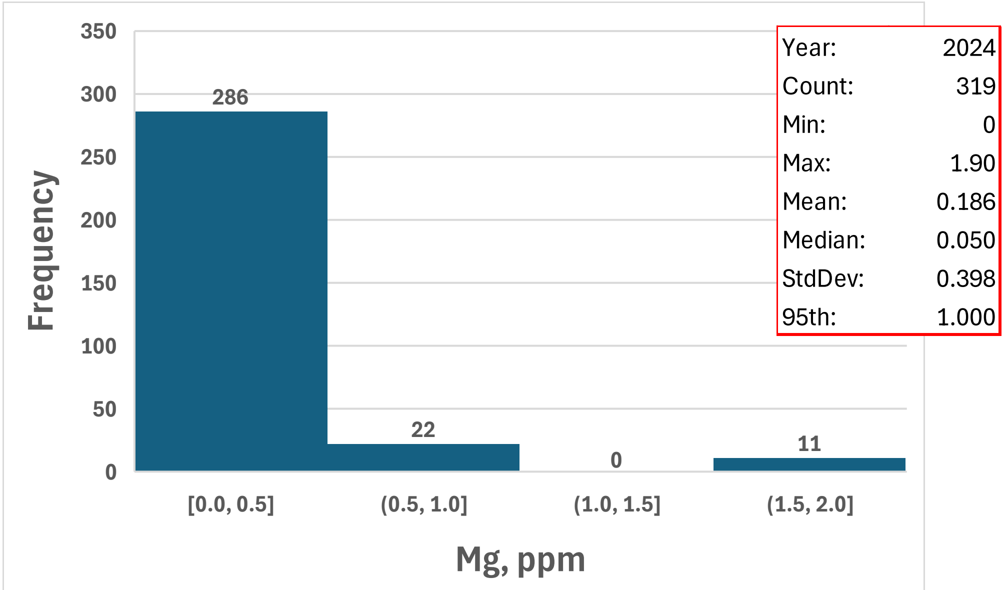

Figure 4. Magnesium content of biodiesel

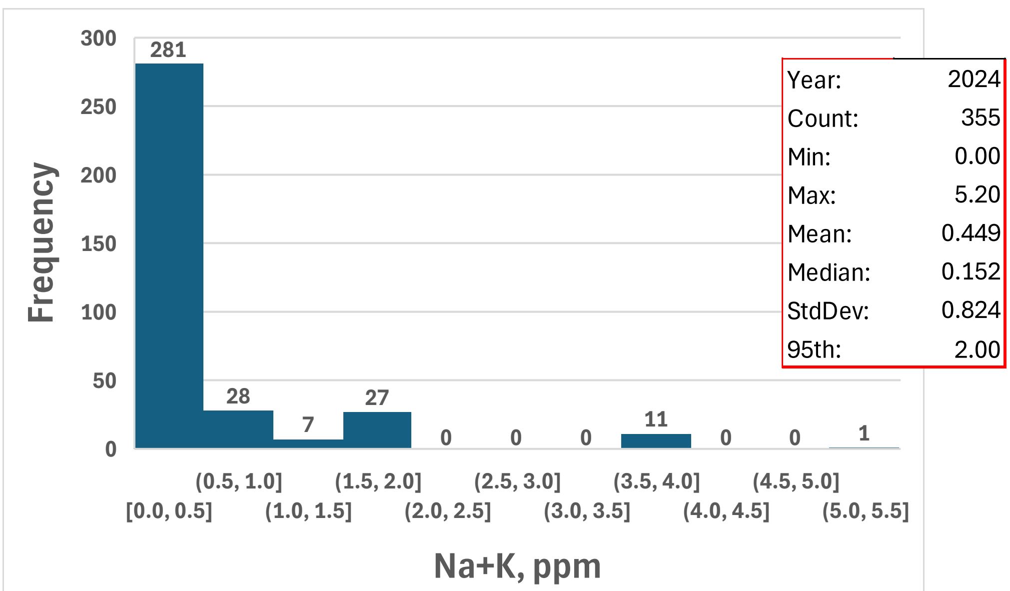

Figure 5. Sodium and potassium content for biodiesel

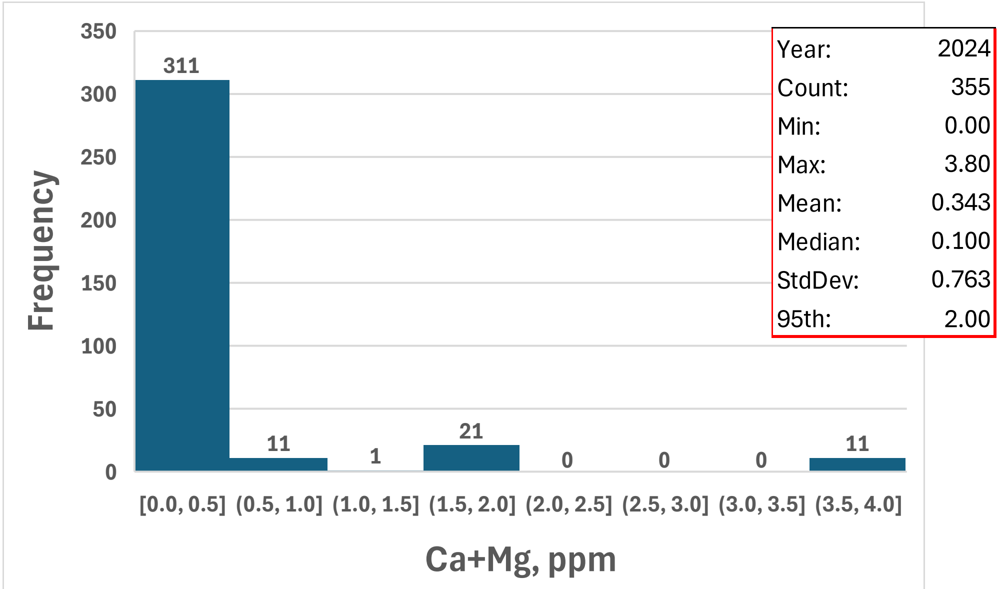

Figure 6. Calcium and magnesium content of biodiesel

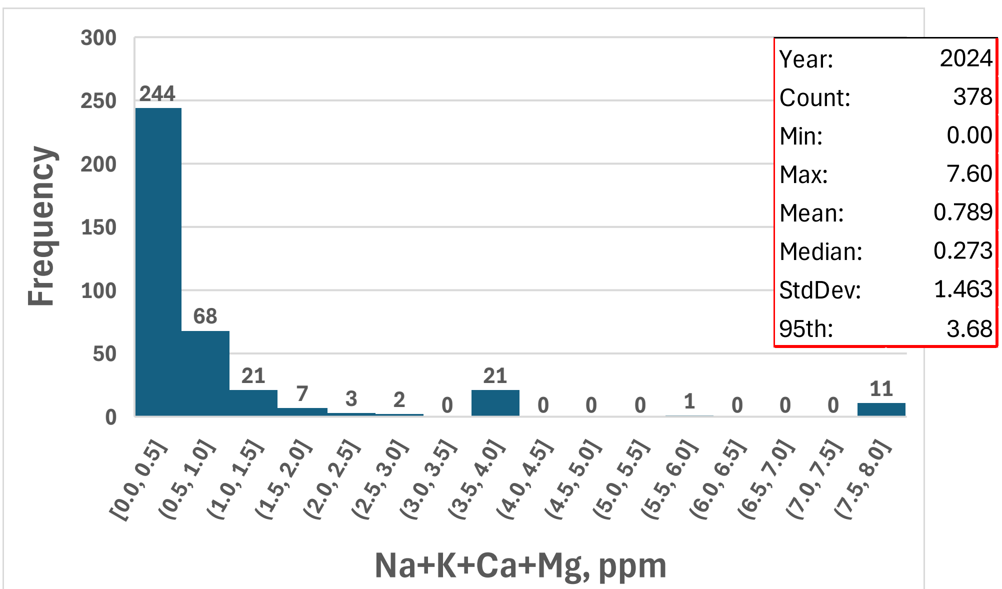

Figure 7. Sodium, potassium, calcium, and magnesium content for biodiesel

3.2 Phosphorus

In 2024, the average phosphorus content was 0.796 ppm, the median value was 0.220 ppm, and the 95th percentile was 4.00 ppm (Figure 8).

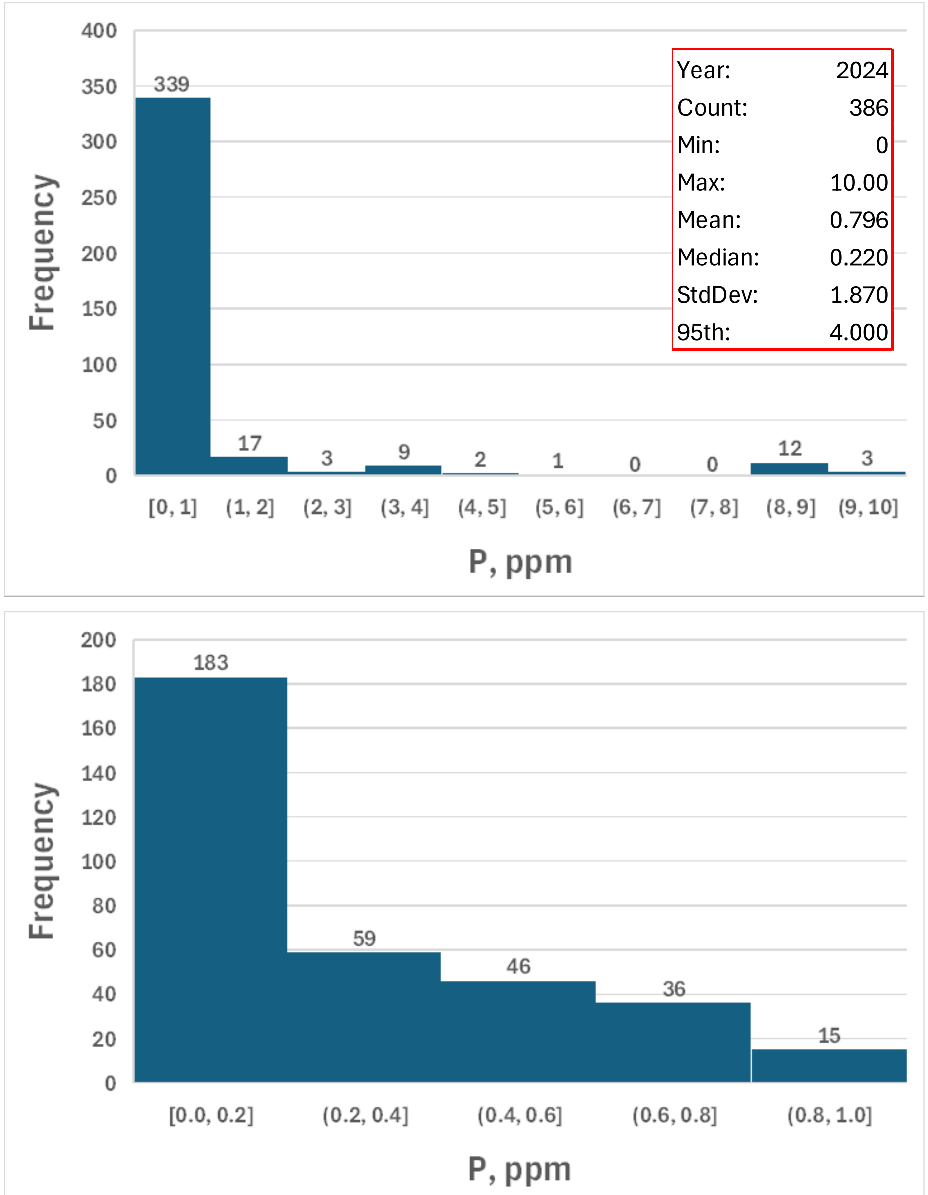

Figure 8. Phosphorus content of biodiesel. The top panel represents all samples, and the bottom panel for phosphorus ≤1 ppm.

3.3 Flash Point and Alcohol Control

Figure 9 shows the flash point analysis. Biodiesel produced in 2024 had an average of 149°C, a median flash point of 153°C, and a 5th percentile of 105°C, meaning that 95% of values were above this level. Average alcohol content was 0.09% mass, with a median of 0.09% mass and a 95th percentile of 0.14% mass (Figure 10).

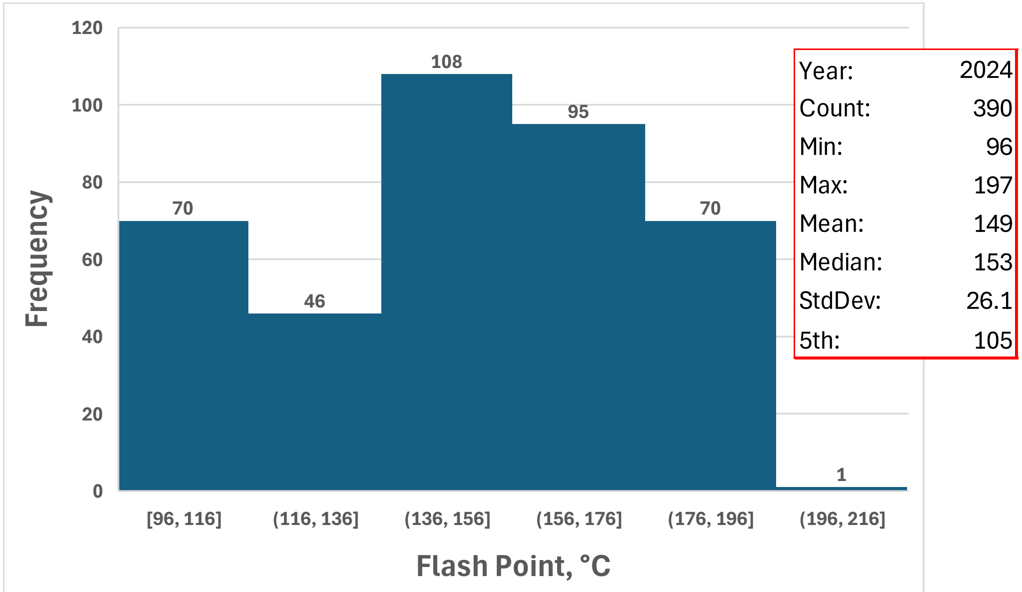

Figure 9. Flash point for biodiesel

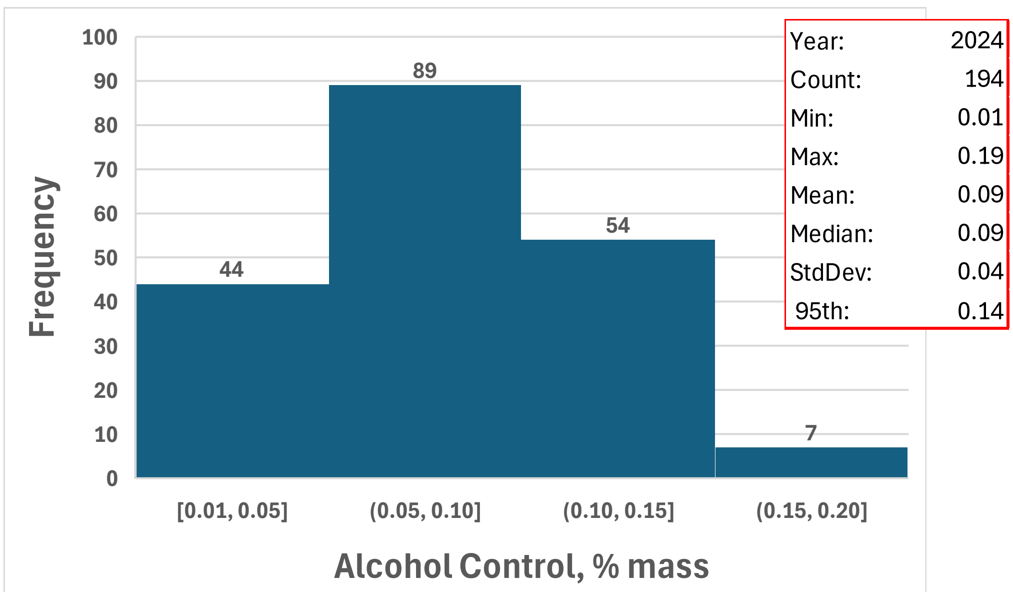

Figure 10. Alcohol control for biodiesel

3.4 Water and Sediment

The results from the water and sediment analysis are shown in Figure 11. The average was 0.005 vol %, the median was 0.000 vol %, and the 95th percentile was 0.017 vol %.

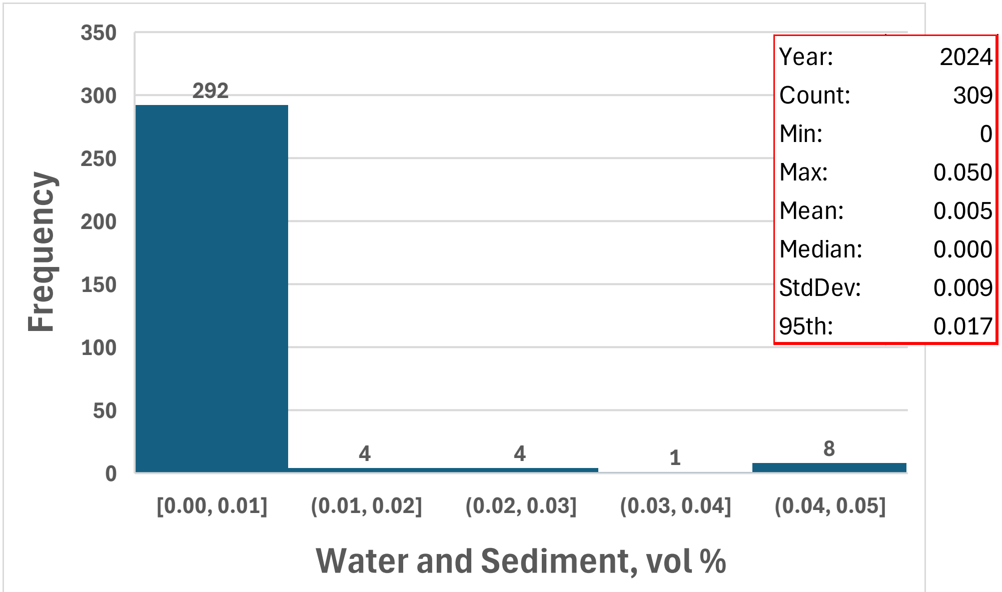

Figure 11. Water and sediment content for biodiesel

3.5 Cloud Point

The cloud point average was 0.68°C, with a median of 0°C and a 95^{t}h percentile of 8.0°C (Figure 12).

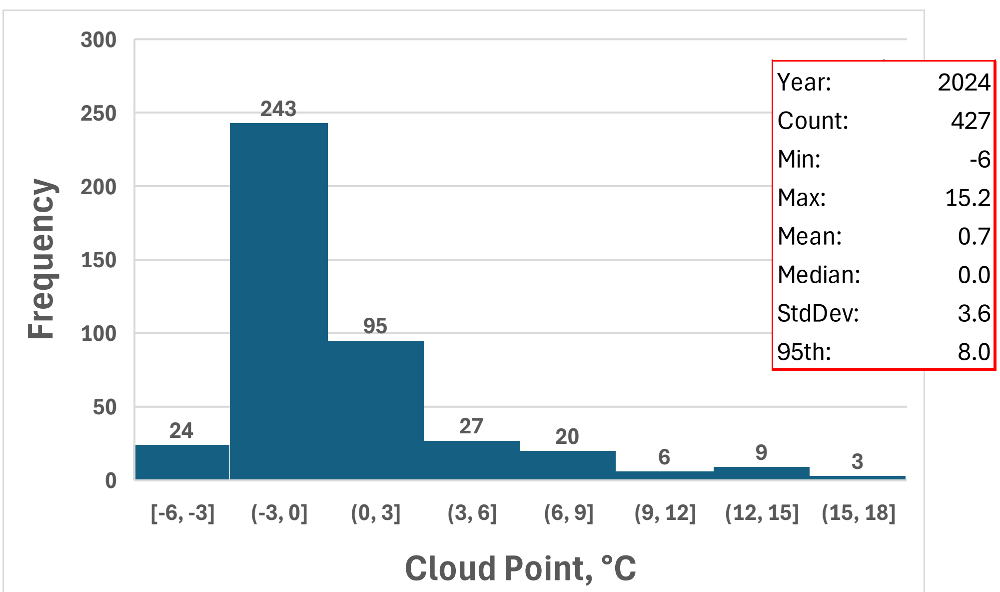

Figure 12. Cloud point results for biodiesel

3.6 Acid Number

Biodiesel in 2024 had average and median acid number results of 0.271 and 0.270 mg KOH/g, respectively, and the 95th percentile was 0.42 mg KOH/g (Figure 13).

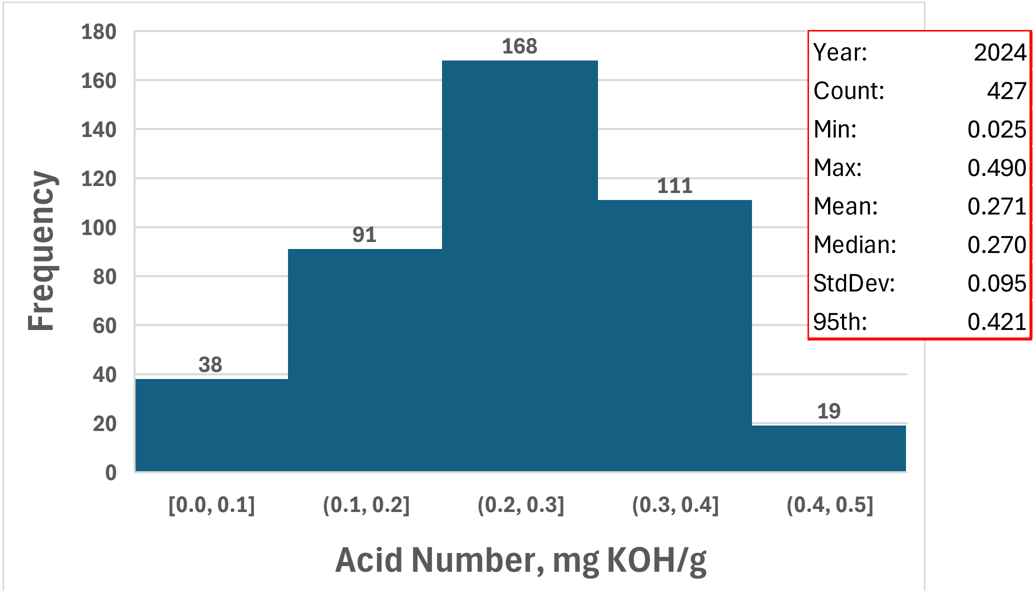

Figure 13. Acid number results for biodiesel

3.7 Free and Total Glycerin and Monoglycerides

Figure 14 shows the average free glycerin of 0.004% mass, median of 0.004% mass, and 95th percentile of 0.01% mass. The total glycerin data are shown in Figure 15. The average was 0.092% mass, the median was 0.104% mass, and the 95th percentile was 0.15% mass.

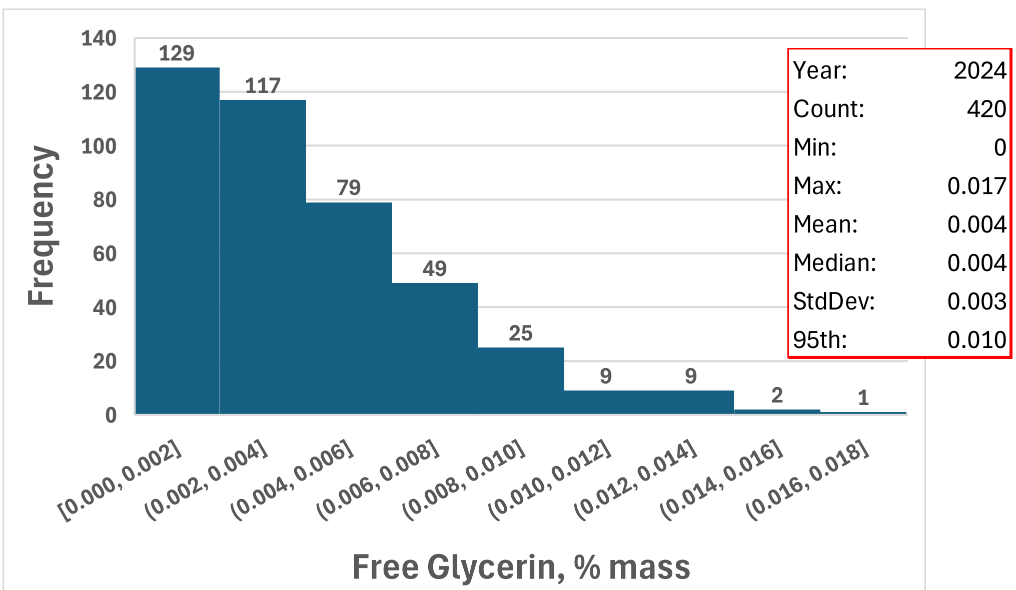

Figure 14. Free glycerin content of biodiesel

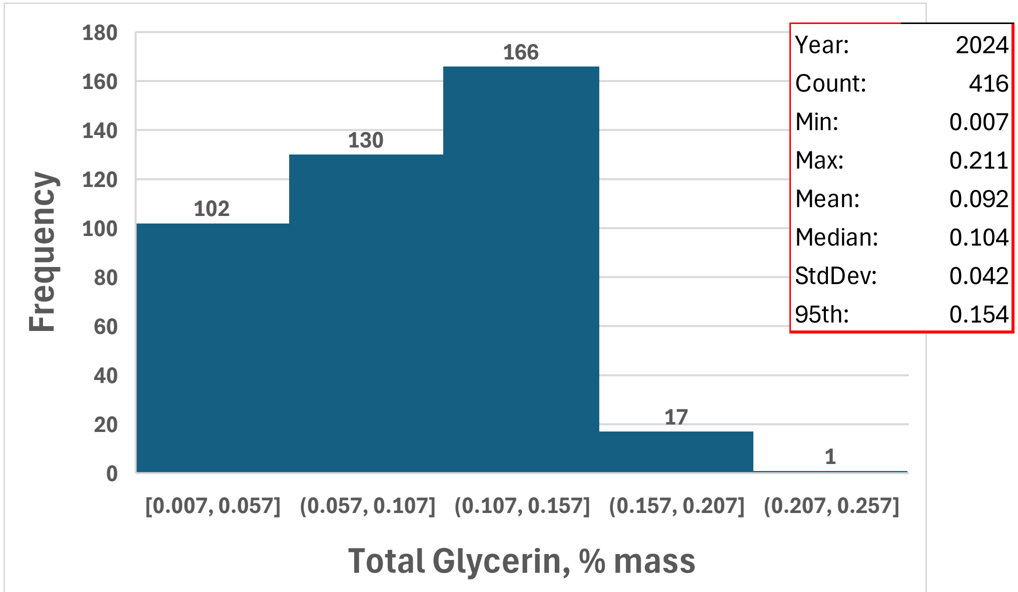

Figure 15. Total glycerin content of biodiesel

Figure 16 shows the distribution of monoglycerides from biodiesel produced in calendar year 2024. The average monoglyceride content was 0.267% mass, the median was 0.308% mass, and the 95th percentile was 0.416% mass.

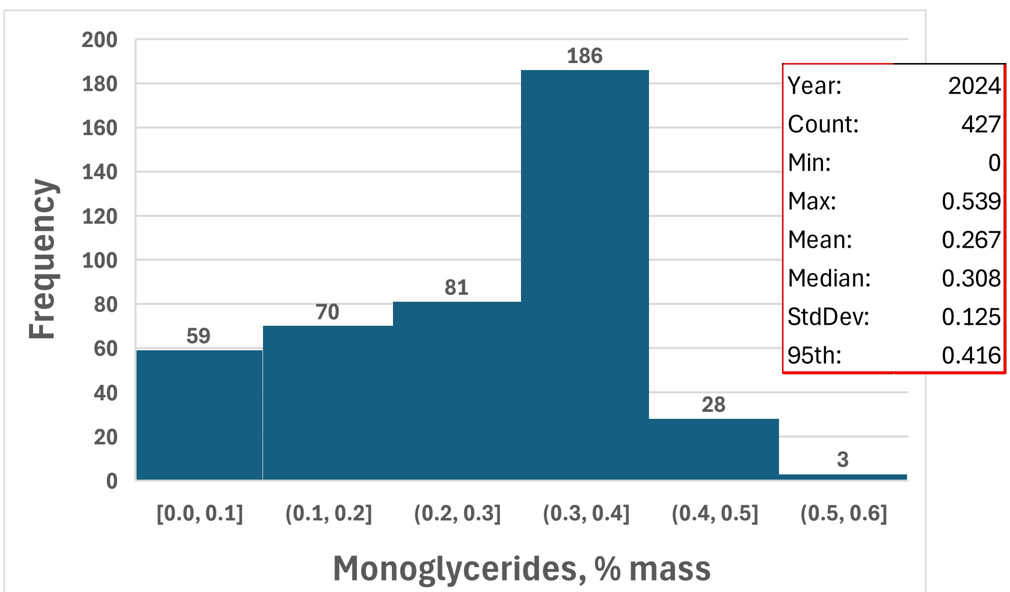

Figure 16. Monoglycerides content of biodiesel

3.8 Sulfur Content

The average sulfur content of biodiesel produced in 2024 was 3.34 ppm, with a median value of 1.60 ppm and a 95th percentile of 12.0 ppm (Figure 17).

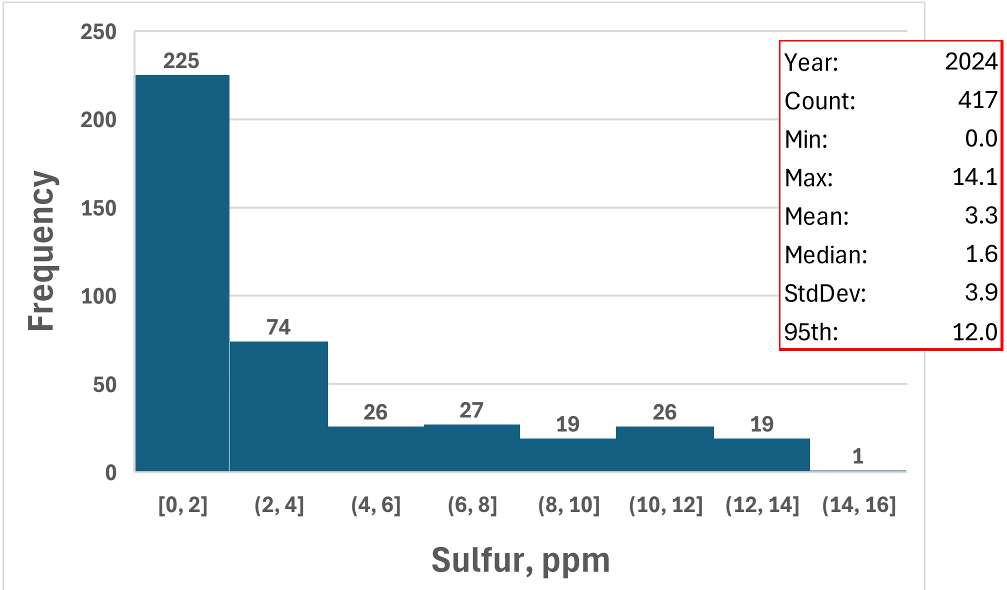

Figure 17. Sulfur content of biodiesel

3.9 Oxidation Stability

The average oxidation stability, shown in Figure 18, was 9.5 hours, with a median of 8.8 hours. The 5th percentile for these samples was 5.87 hours.

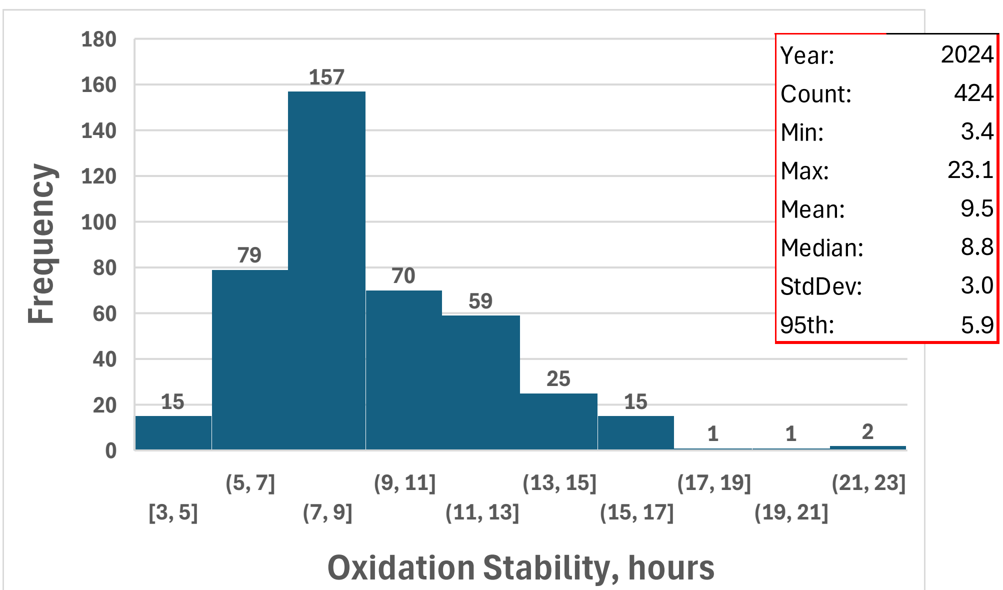

Figure 18. Oxidation stability results for biodiesel

3.10 Cold Soak Filterability Test

Biodiesel produced in 2024 had an average CSFT result of 101 seconds, a median of 94 seconds, and a 95th percentile of 155 seconds (Figure 19).

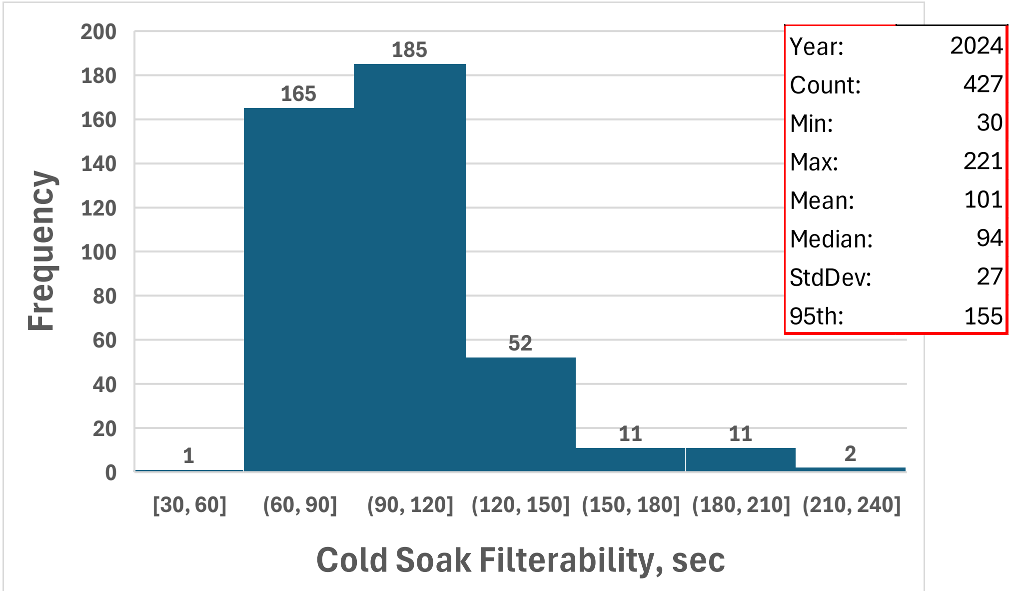

Figure 19. CSFT results for biodiesel

3.11 Kinematic Viscosity

The average kinematic viscosity of biodiesel produced in 2024 was 4.3 mm/s^2, with a median of 4.2 mm/s^2 and a 95th percentile of 4.8 mm/s^2 (Figure 20).

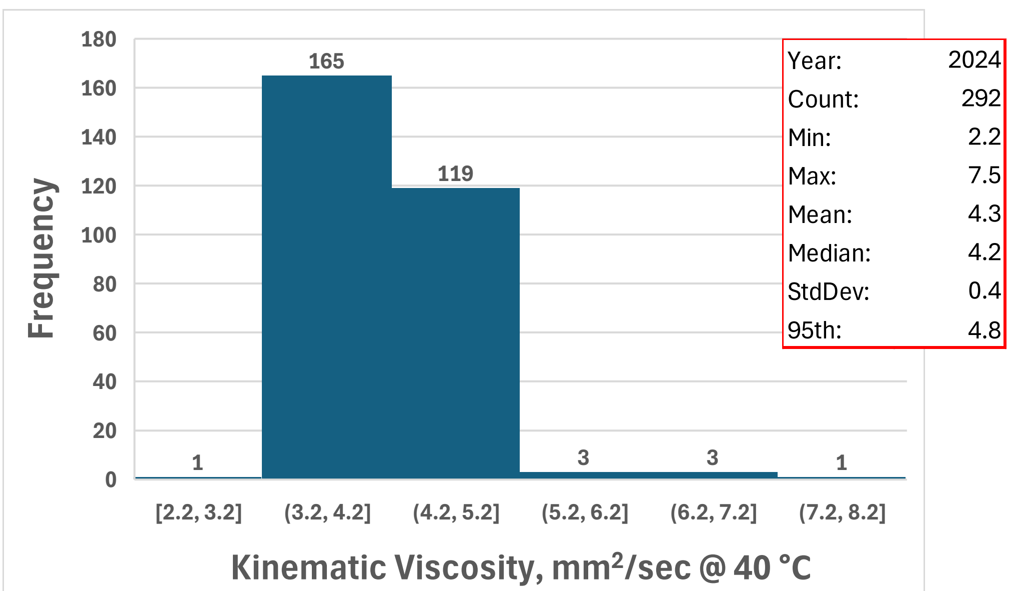

Figure 20. Kinematic viscosity at 40°C results for biodiesel

3.12 Sulfated Ash

Figure 21 shows the variance in sulfated ash from biodiesel in calendar year 2024. The average, median, and 95th percentile values were 0.003 % mass, 0.002 % mass, and 0.006 % mass, respectively.

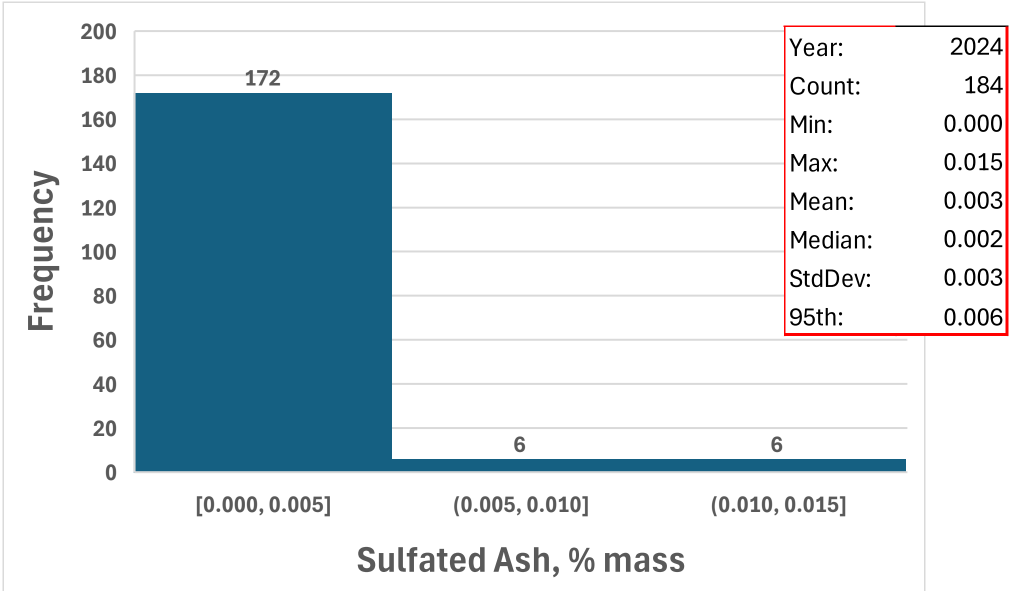

Figure 21. Sulfated ash results for biodiesel

3.13 Distillation Temperature, T90

Data for distillation temperature, T90, are presented in Figure 22. The average and median were both 353°C, and the 95th percentile was 355°C.

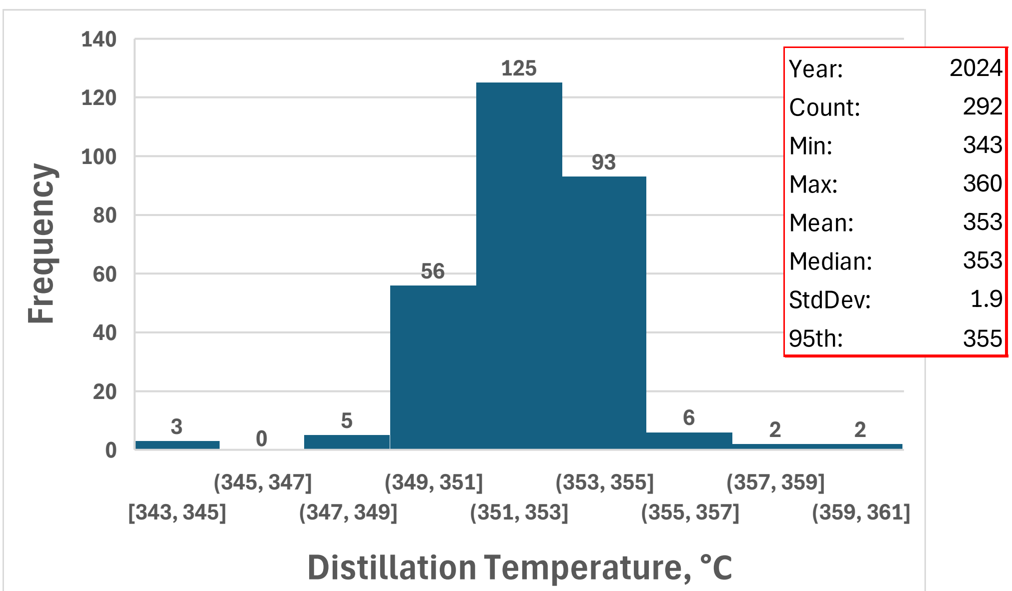

Figure 22. Distillation temperature (T90) results for biodiesel

3.14 Carbon Residue

Figure 23 shows the values (% mass) for carbon residue measured on the B100. Biodiesel produced in 2024 had an average of 0.01 % mass, a median of 0.001 % mass, and a 95th percentile of 0.03 % mass, meaning that 95% of values were above this level.

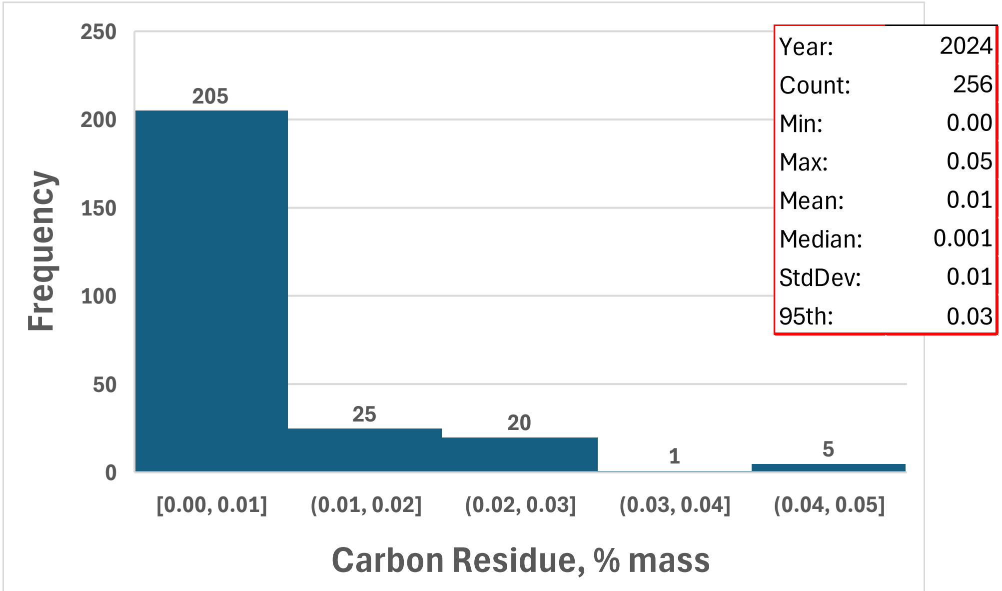

Figure 23. Carbon residue results for biodiesel

3.15 Cetane Number

Biodiesel produced in 2024 had an average cetane number of 50.9, a median of 50.2, and a 95th percentile of 59.1 (Figure 24).

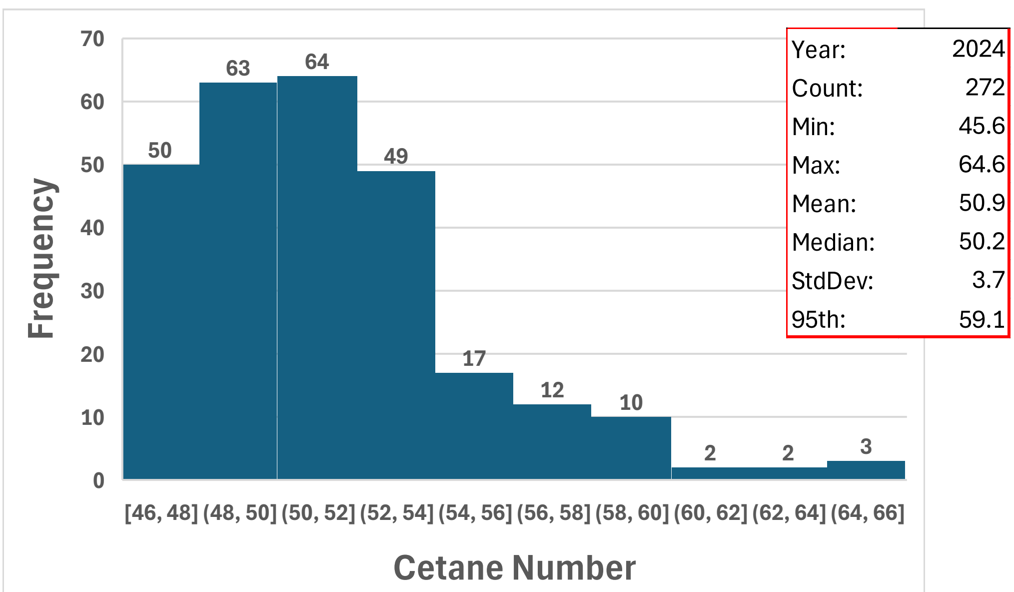

Figure 24. Cetane number results for biodiesel

4 Summary

We analyzed monthly quality data voluntarily provided by BQ-9000 biodiesel producers in the United States and Canada for calendar year 2024. This is the eighth in a series of reports on the subject. Monthly quality data were submitted to a third-party team that removed any identifying company information before providing it to NREL. Our statistical results are summarized in Table 1. The data were not weighted for production volume, and binning was selected for ease of data presentation.

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a Run on the B100 sample. Note: Flash Point and Oxidation Stability are 5th percentile.

5 References

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McCormick, Robert L. 2024. *Assessment of BQ-9000 Biodiesel Properties for 2023.* Golden, CO: National Renewable Energy Laboratory. NREL/TP-4A00-86227. https://www.nrel.gov/docs/fy24osti/90280.pdf

6 Appendix

Data presented in this appendix represent "all data" voluntarily supplied for analysis. For these figures, any data that included "greater than" or "less than" were assumed to be equal to the value reported. As an example, Na + K data reported as <5 ppm were included as 5 ppm in this appendix. The purpose of including the data here is to best capture the data on biodiesel quality in calendar year 2024. Due to the nonstandard treatment of the data, no statistical analysis of appendix data was performed.

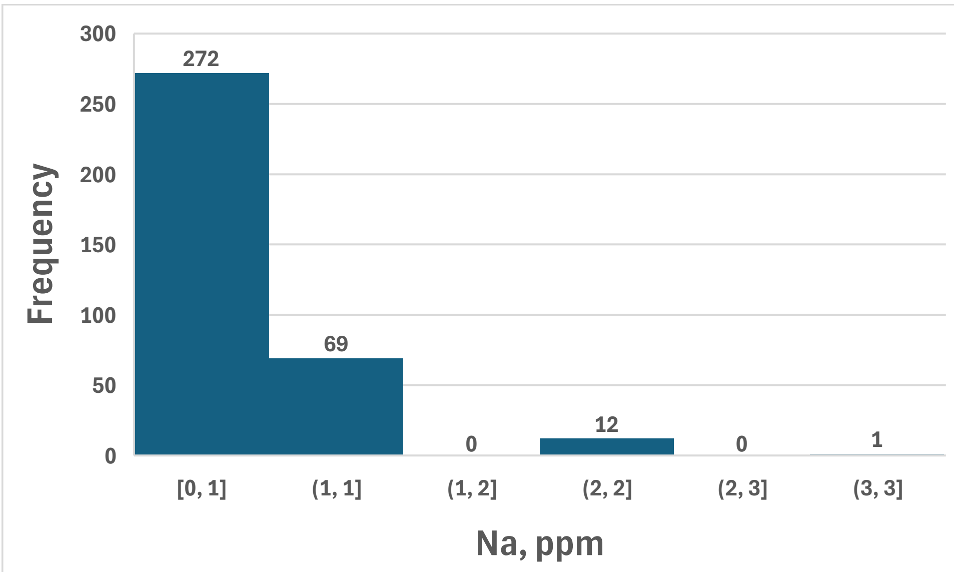

Figure A-1. All data analysis of sodium content of biodiesel.

Data reported as "greater than X" or "less than X" were assumed to have a value of X

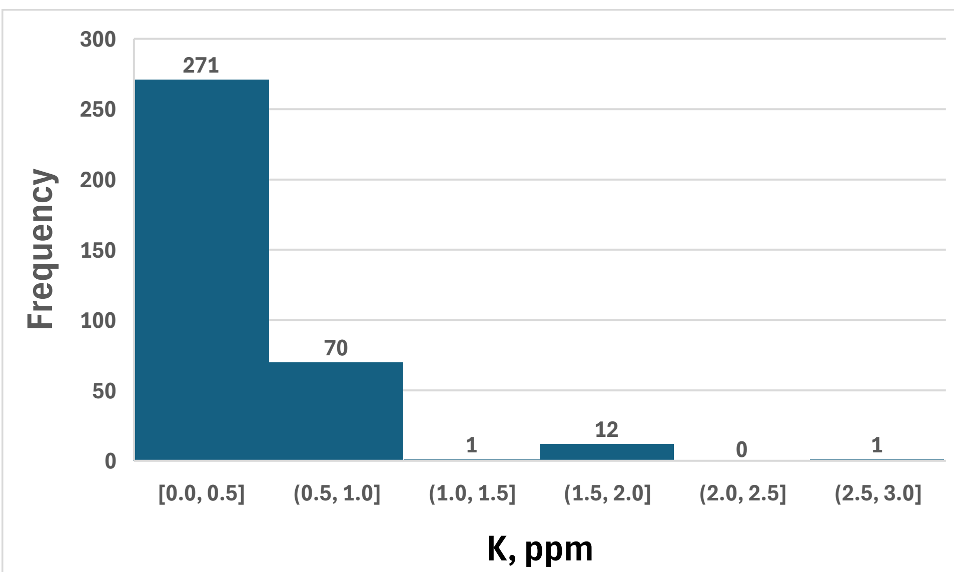

Figure A-2. All data analysis of potassium content of biodiesel.

Data reported as "greater than X" or "less than X" were assumed to have a value of X

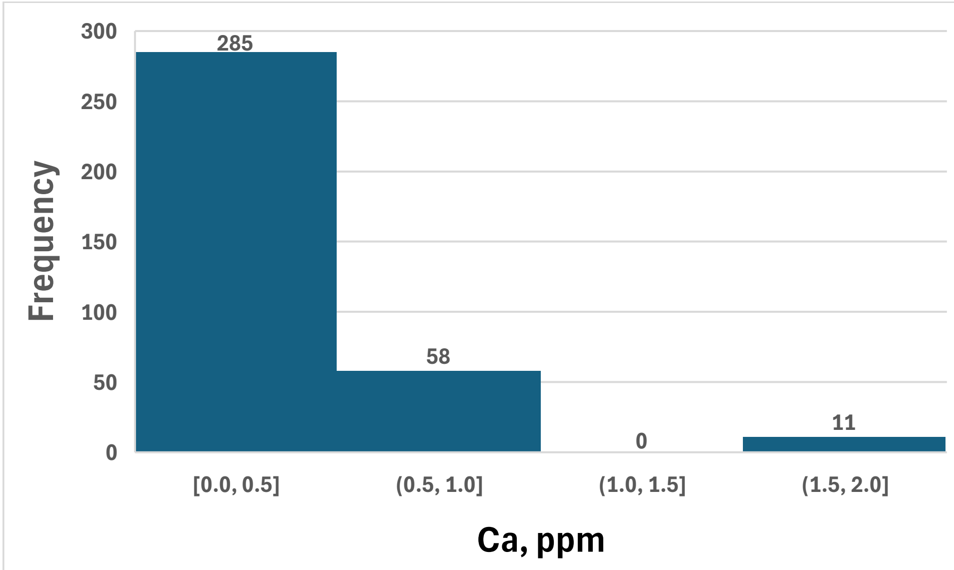

Figure A-3. All data analysis of calcium content of biodiesel.

Data reported as “greater than X” or “less than X” were assumed to have a value of X

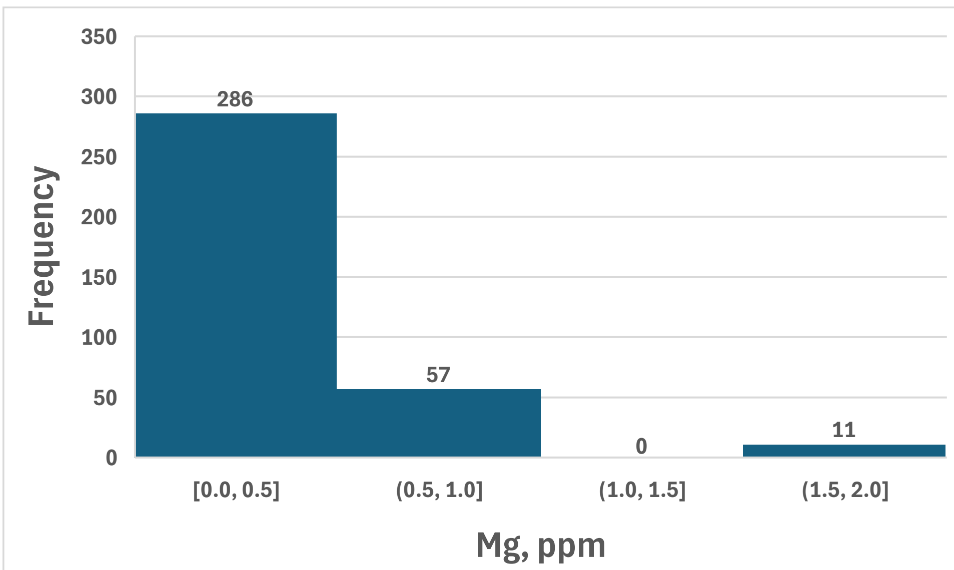

Figure A-4. All data analysis of magnesium content of biodiesel.

Data reported as “greater than X” or “less than X” were assumed to have a value of X

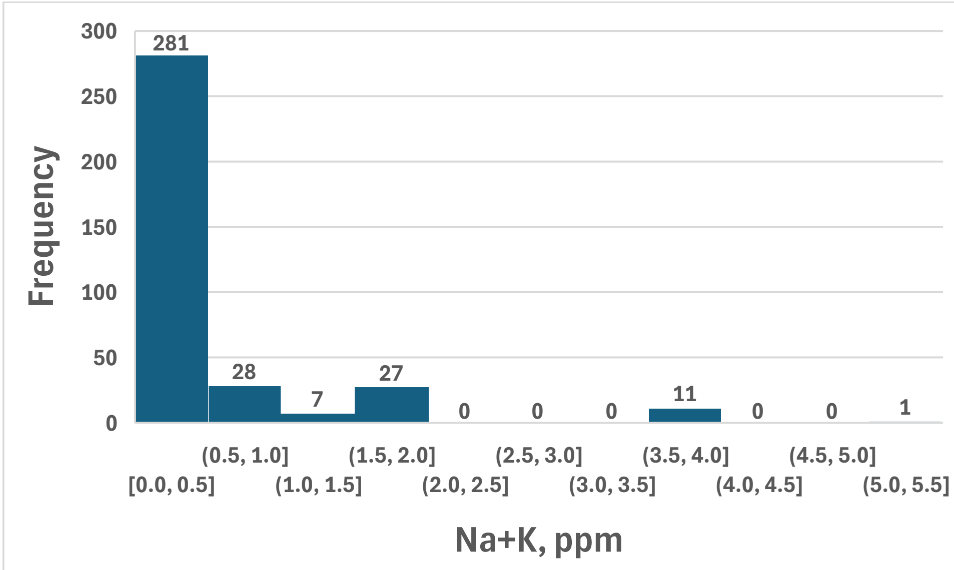

Figure A-5. All data analysis of sodium and potassium content of biodiesel.

Data reported as "greater than X" or "less than X" were assumed to have a value of X

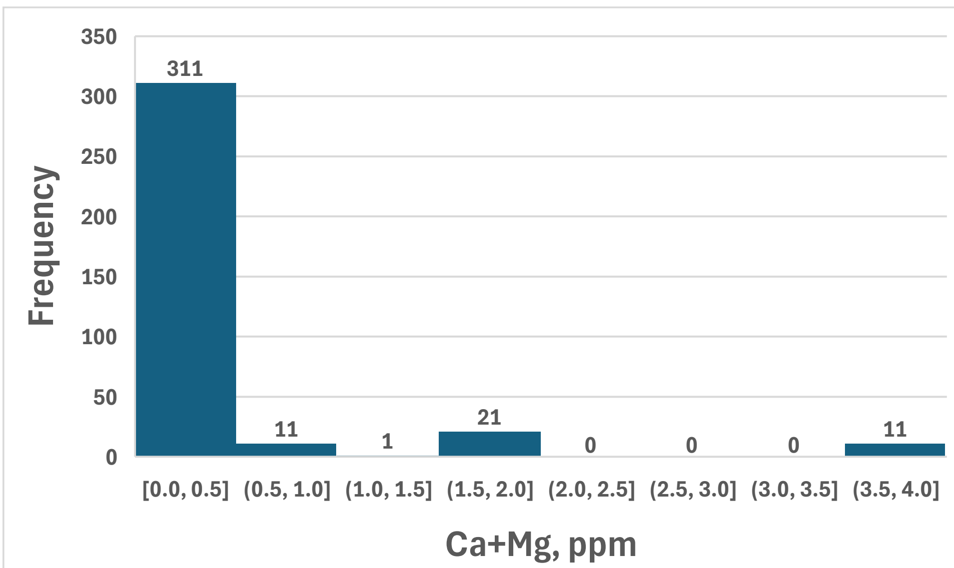

Figure A-6. All data analysis of calcium and magnesium content of biodiesel.

Data reported as "greater than X" or "less than X" were assumed to have a value of X

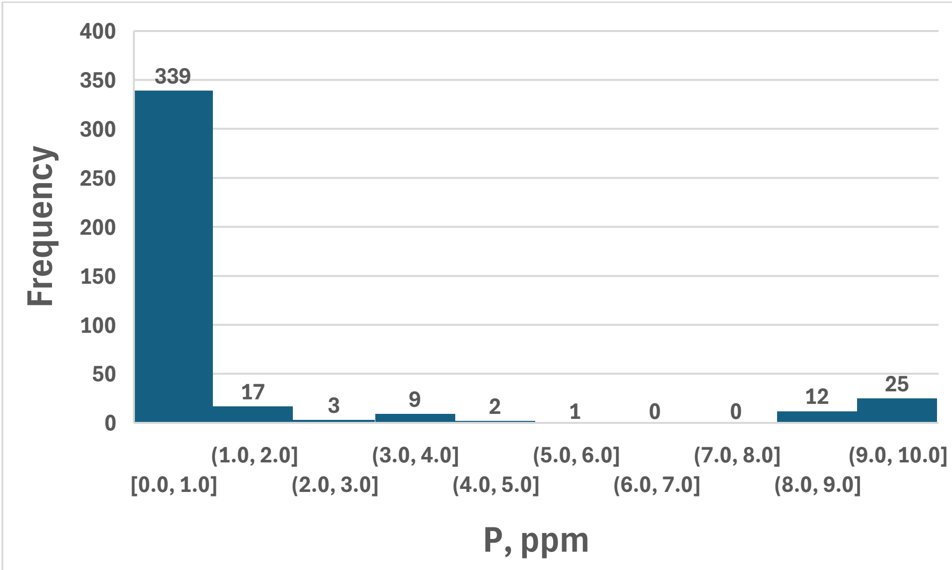

Figure A-7. All data analysis of phosphorus content of biodiesel.

Data reported as “greater than X” or “less than X” were assumed to have a value of X

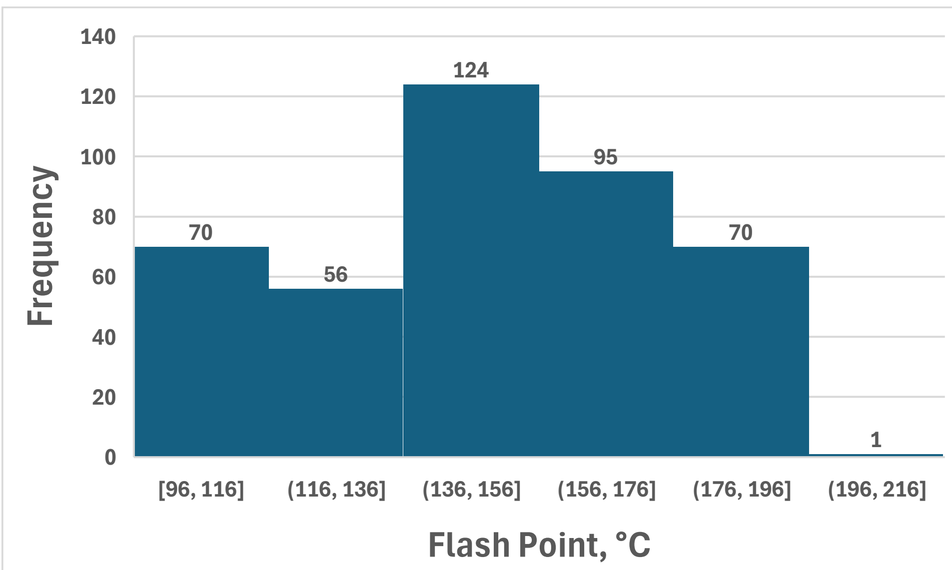

Figure A-8. All data analysis of flash point of biodiesel.

Data reported as “greater than X” or “less than X” were assumed to have a value of X

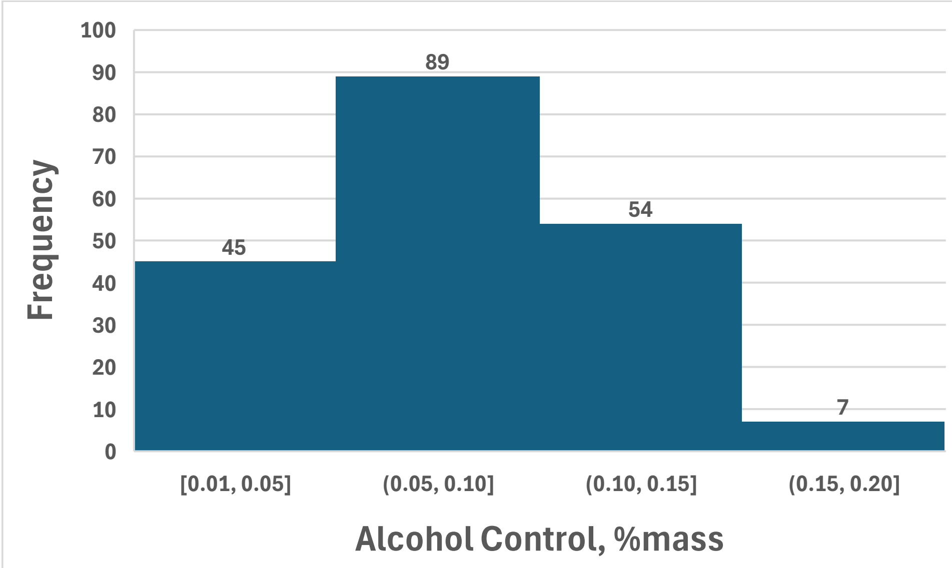

Figure A-9. All data analysis of alcohol control of biodiesel.

Data reported as “greater than X” or “less than X” were assumed to have a value of X

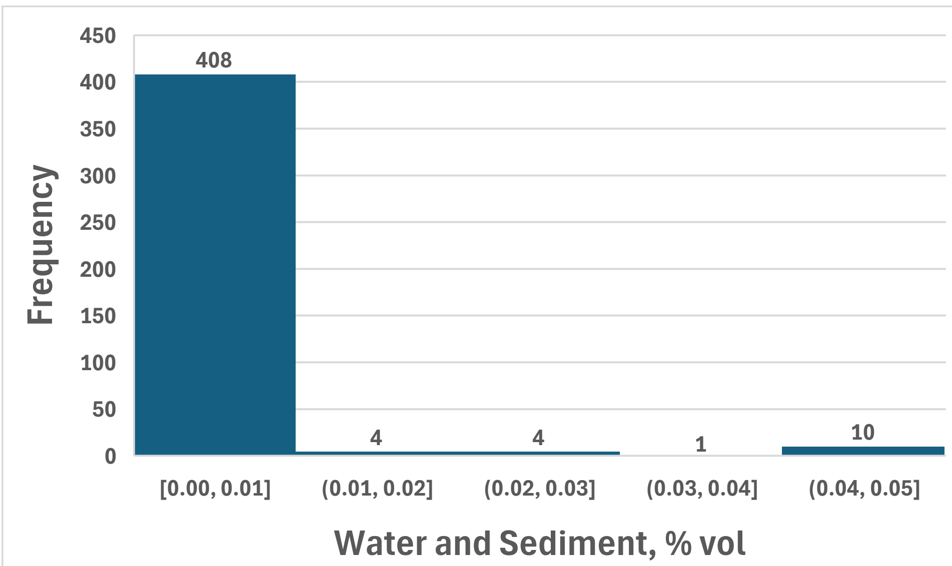

Figure A-10. All data analysis of water and sediment content of biodiesel.

Data reported as “greater than X” or “less than X” were assumed to have a value of X

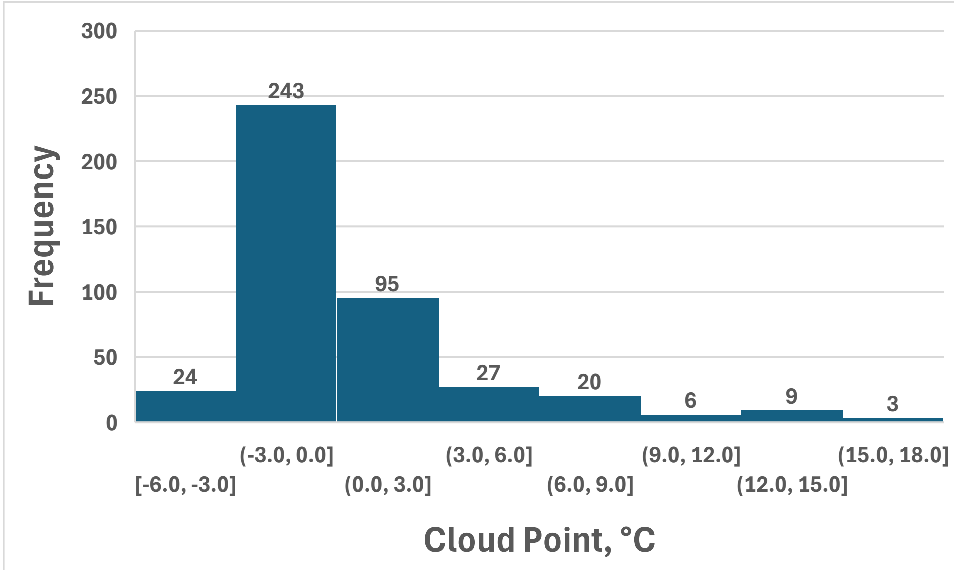

Figure A-11. All data analysis of cloud point of biodiesel.

Data reported as “greater than X” or “less than X” were assumed to have a value of X

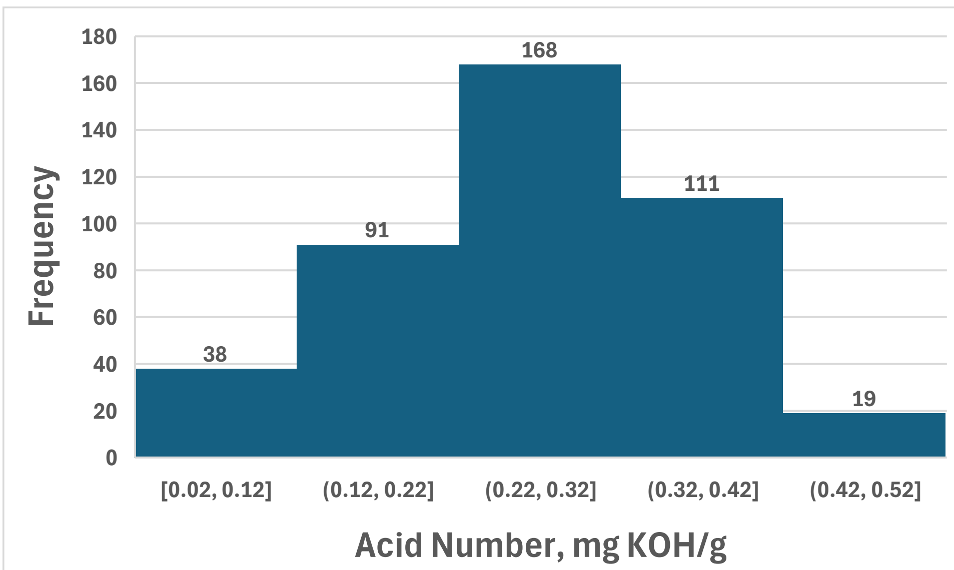

Figure A-12. All data analysis of acid number of biodiesel.

Data reported as “greater than X” or “less than X” were assumed to have a value of X

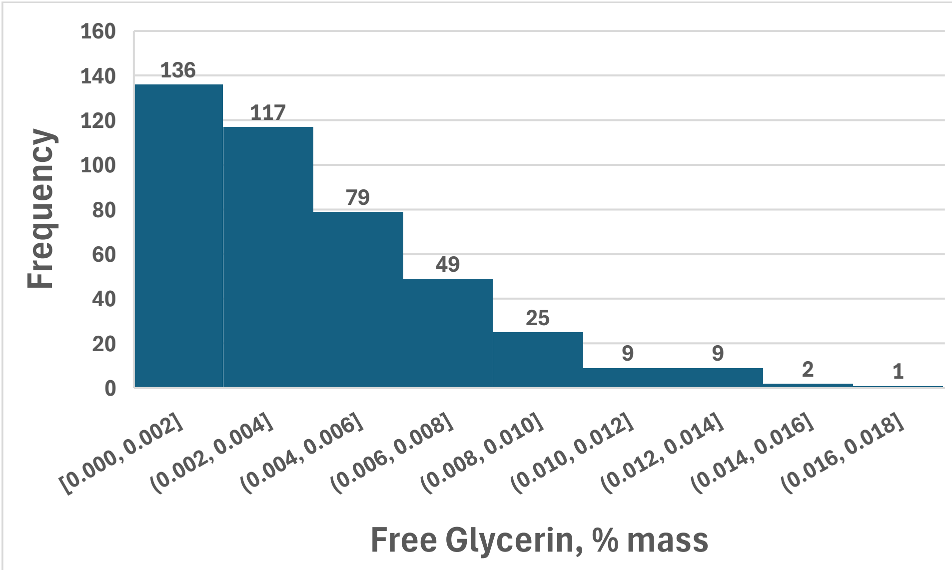

Figure A-13. All data analysis of free glycerin content of biodiesel.

Data reported as "greater than X" or "less than X" were assumed to have a value of X

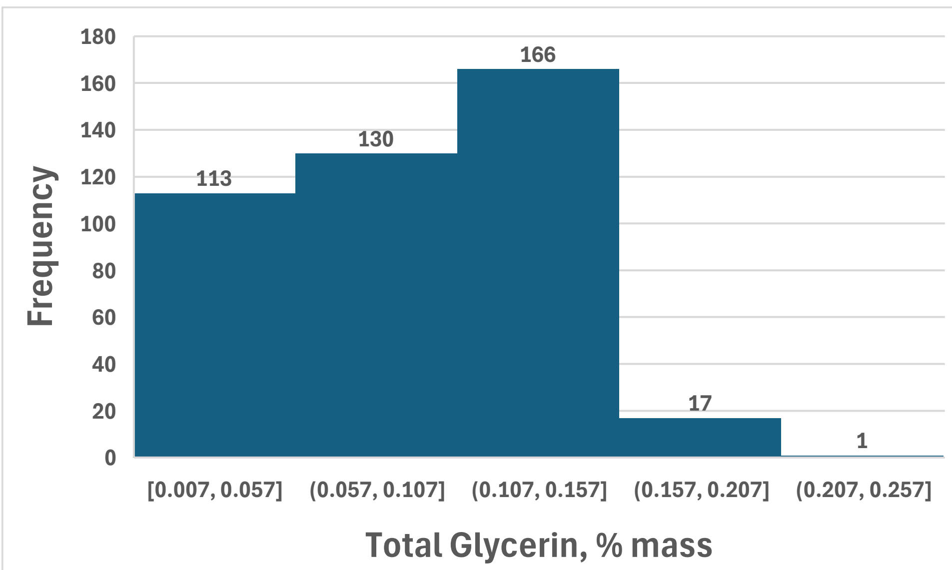

Figure A-14. All data analysis of total glycerin content of biodiesel.

Data reported as "greater than X" or "less than X" were assumed to have a value of X

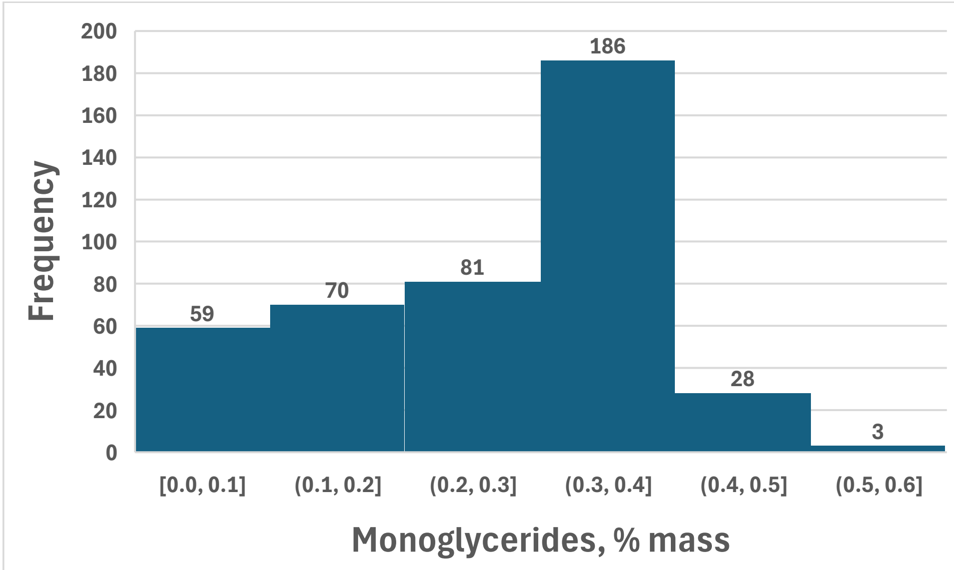

Figure A-15. All data analysis of monoglycerides content of biodiesel.

Data reported as “greater than X” or “less than X” were assumed to have a value of X

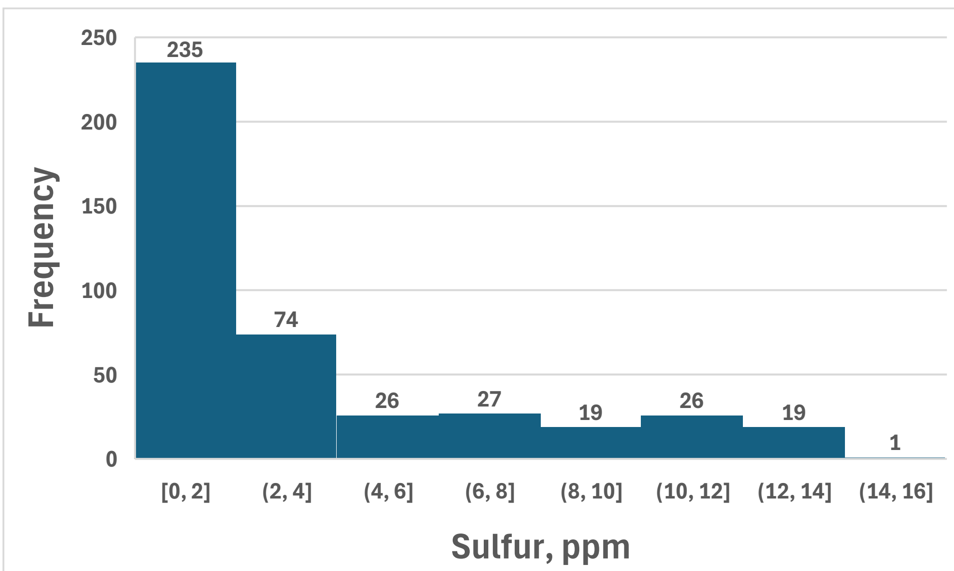

Figure A-16. All data analysis of sulfur content of biodiesel.

Data reported as “greater than X” or “less than X” were assumed to have a value of X

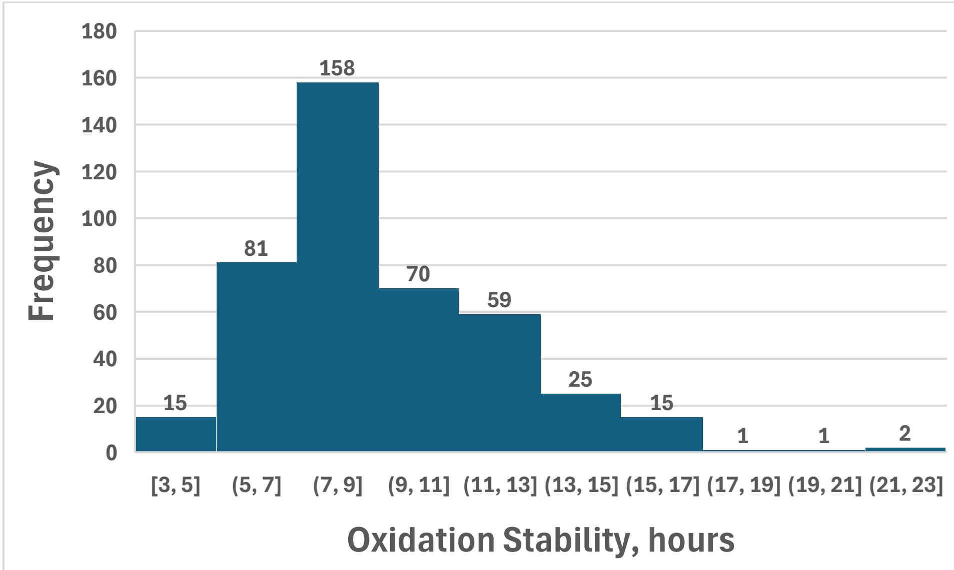

Figure A-17. All data analysis of oxidation stability of biodiesel.

Data reported as "greater than X" or "less than X" were assumed to have a value of X

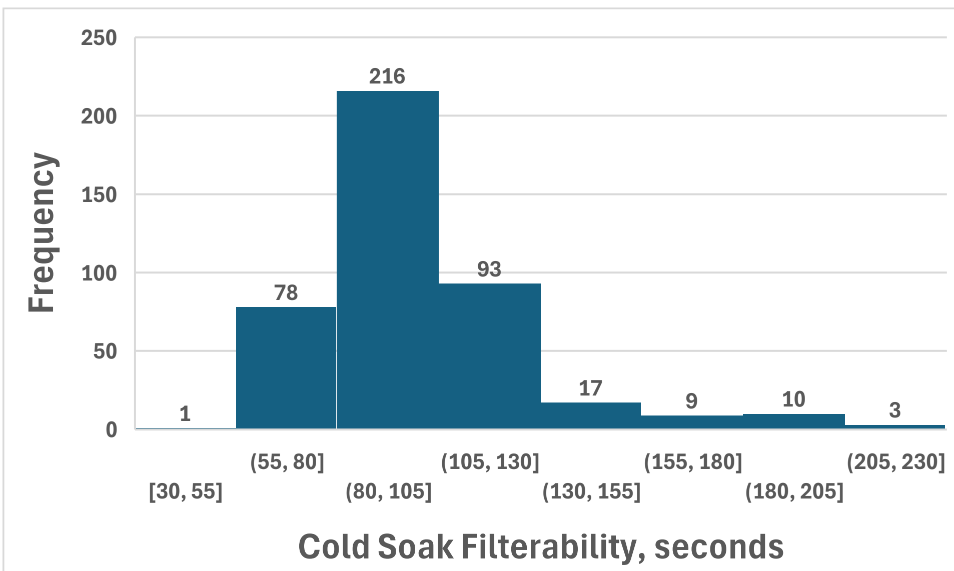

Figure A-18. All data analysis of CSFT of biodiesel.

Data reported as "greater than X" or "less than X" were assumed to have a value of X

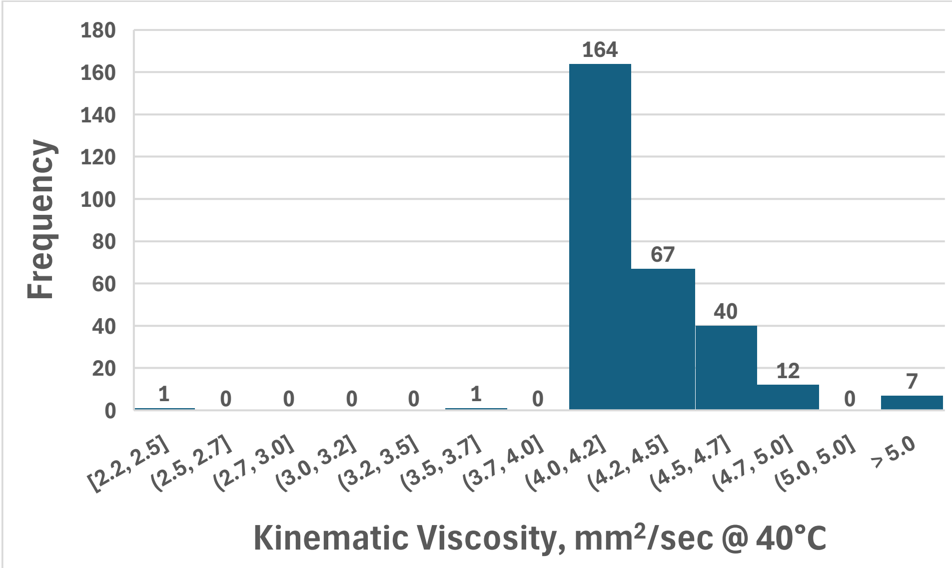

Figure A-19. All data analysis of kinematic viscosity of biodiesel.

Data reported as "greater than X" or "less than X" were assumed to have a value of X

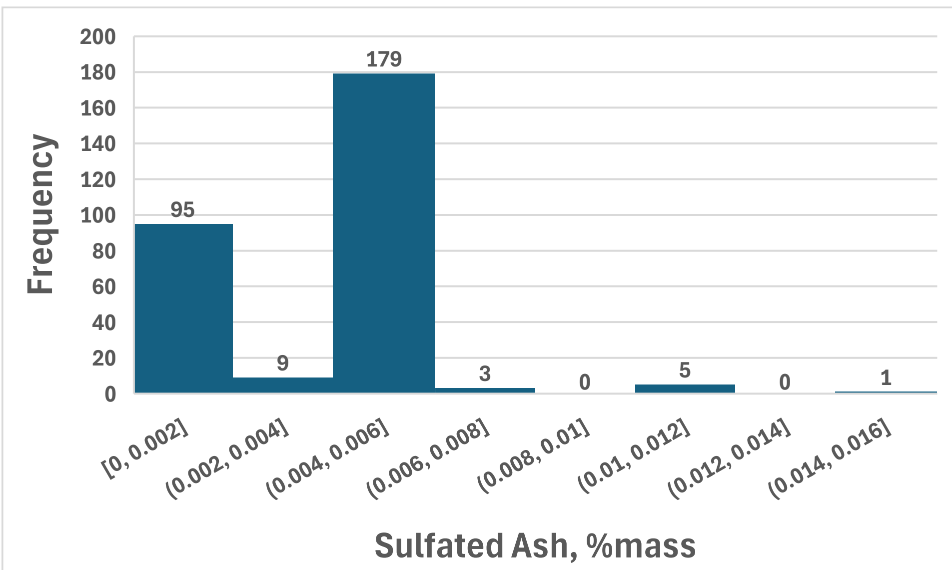

Figure A-20. All data analysis of sulfated ash of biodiesel.

Data reported as "greater than X" or "less than X" were assumed to have a value of X

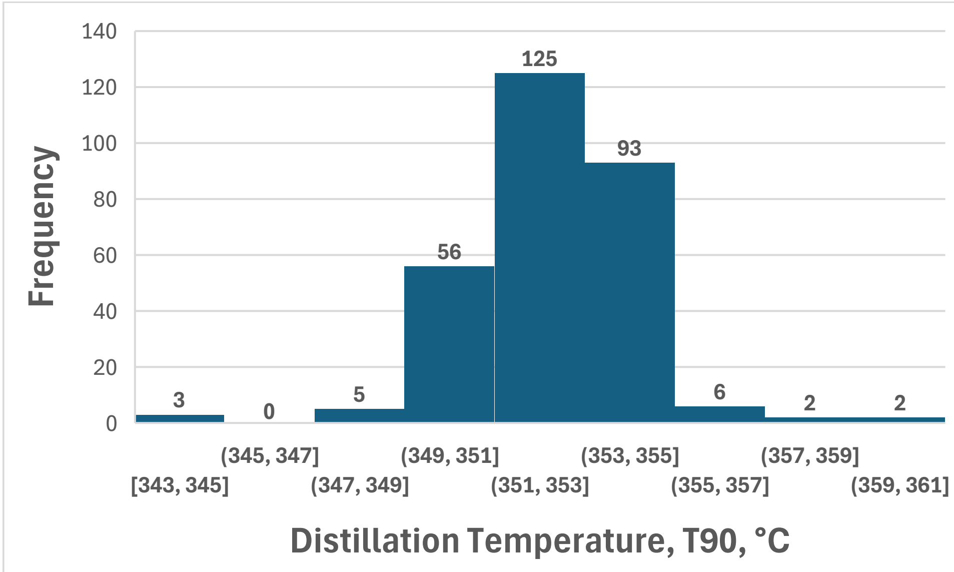

Figure A-21. All data analysis of distillation temperature, T90, of biodiesel.

Data reported as “greater than X” or “less than X” were assumed to have a value of X

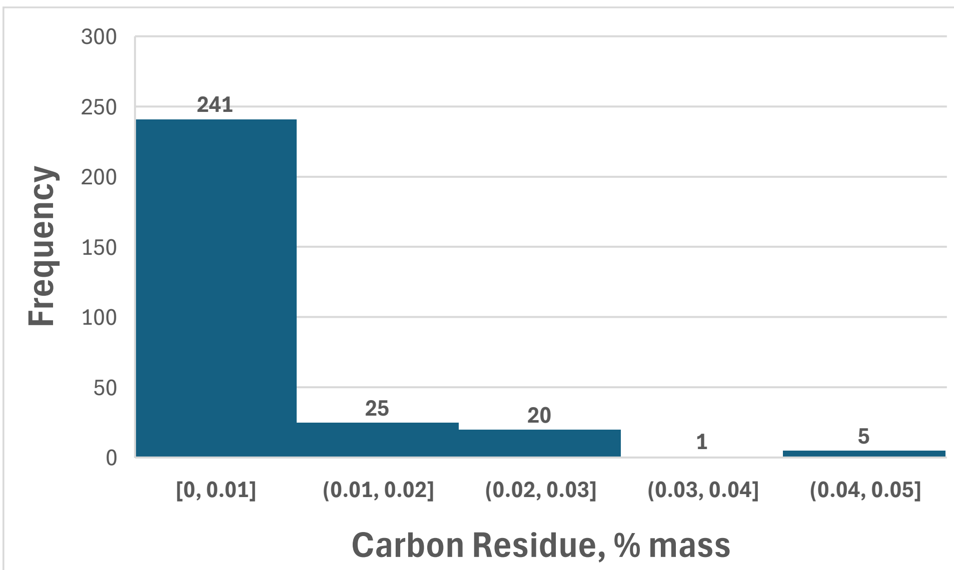

Figure A-22. All data analysis of carbon residue of biodiesel.

Data reported as “greater than X” or “less than X” were assumed to have a value of X

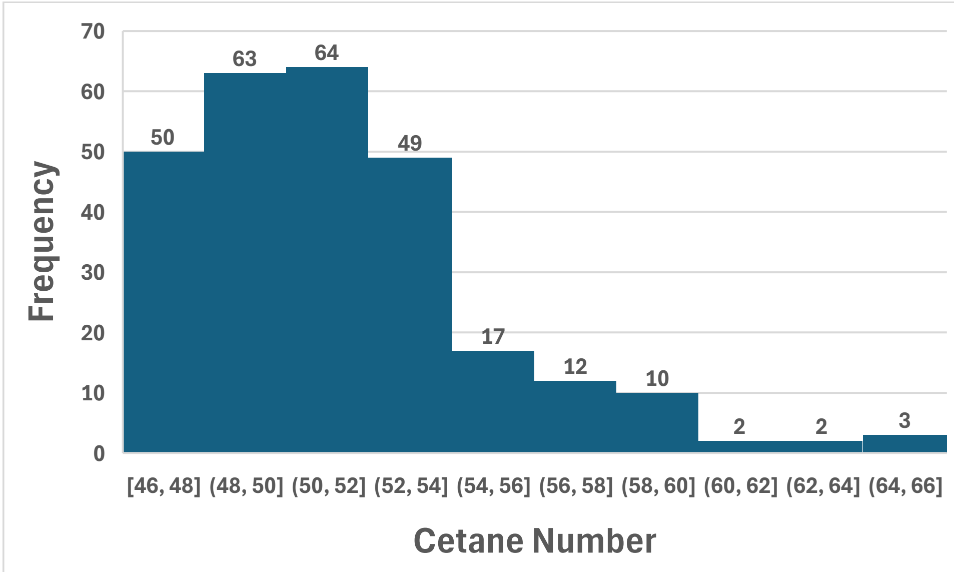

Figure A-23. All data analysis of cetane number of biodiesel.

Data reported as “greater than X” or “less than X” were assumed to have a value of X