



Assessment of BQ-9000 Biodiesel Properties for 2021

Teresa L. Alleman

National Renewable Energy Laboratory

Produced under direction of Clean Fuels Alliance America by the National Renewable Energy Laboratory (NREL) under Cooperative Research and Development Agreement CRC-15-593.

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Strategic Partnership Project Report
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Acknowledgments

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List of Acronyms

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

Executive Summary

This is the fifth 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 voluntary quality assurance program. Participants agreed to provide monthly data on critical quality parameters for calendar year 2021. The quality data were provided to a team of experts, who removed any identifying company information and provided anonymized and randomized data to the National Renewable Energy Laboratory (NREL) for statistical analysis. The critical quality parameters analyzed were sodium and potassium (Na+K), calcium and magnesium (Ca+Mg), phosphorus (P), flash point and alcohol control, water and sediment, cloud point, acid number, free and total glycerin, monoglycerides, sulfur, oxidation stability, and cold soak filterability test (CSFT). The data were not weighted for production volume. The results of our analysis are presented in Table ES-1.

Table ES-1. BQ-9000 Critical Parameter Summary, Calendar Year 2021

BQ-9000 Parameter	# of Values Reported	Minimum	Maximum	Average	Median	Standard Deviation	95th Percentile
Na+K, ppm	382	0	3.5	0.43	0.20	0.60	1.7
Ca+Mg, ppm	382	0	1.7	0.11	0.00	0.24	0.60
P, ppm	376	0	10	0.9	0.07	2.4	10
Flash point, °C	454	95	193	152	158	24	103 ^a
Alcohol control, mass %	96	0.06	0.40	0.11	0.11	0.04	0.16
Water and sediment, vol %	275	0.00	0.020	0.001	0.000	0.003	0.010
Cloud point, °C	461	-5	14	1.6	0.25	4.4	9.1
Acid number, mg KOH/g	473	0.04	0.50	0.27	0.27	0.10	0.44
Free glycerin, mass %	435	0.000	0.080	0.006	0.005	0.005	0.012
Total glycerin, mass %	474	0.000	0.207	0.084	0.092	0.043	0.150
Monoglycerides, mass %	474	0.000	0.580	0.247	0.274	0.126	0.396
Sulfur, ppm	470	0	18.7	4	2.5	3.9	11
Oxidation stability, h	474	3.8	23.1	9.4	9.0	3.0	5.5 ^a
CSFT, sec	462	58	316	110	104	35	168

^a Data for 5th percentile

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1 Introduction

This is the fifth in a series of reports that documents the quality of biodiesel produced in the United States and Canada. The National Renewable Energy Laboratory (NREL) and Clean Fuels Alliance America collected and analyzed monthly quality data from BQ-9000¹ producers (Alleman 2020a, 2020b, 2020c, 2021). Producers were asked to voluntarily submit data for analysis and inclusion in the report.

The purpose of this report is to document critical fuel quality parameters for biodiesel for calendar year 2021. These quality parameters are:

- Sodium and potassium (Na+K)
- Calcium and magnesium (Ca+Mg)
- Phosphorus (P)
- 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).

2 Methods

Mr. Steve Howell (MARC-IV Consulting), Mr. Scott Fenwick (Clean Fuels Alliance America), and Dr. Richard Nelson (Enersol Resources) contacted all BQ-9000 producers to request submission of monthly quality data for calendar year 2021. Upon receipt of the data, all company identifying information was removed and the data randomized. 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 D6751-20a, 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. In an effort to capture this information, the data have been summarized in the appendix. For the data in the appendix, any values reported as “greater” or “less” than were assigned that value prior to

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

providing the data to NREL. For example, if a flash point was reported as $>150^{\circ}\text{C}$, the analysis in the appendix assumes the value was 150°C . No statistics were calculated for these data.

3 Results

The significance of the parameters included here are discussed in ASTM International specification D6751-20a, *Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels* (ASTM 2020). All the data presented in both the body and 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 Sodium and Potassium

Figure 1 illustrates the sodium and potassium content of biodiesel produced in 2021. The average Na+K was 0.43 parts per million (ppm), with a median of 0.20 ppm and a 95th percentile of 1.7 ppm (Figure 1).

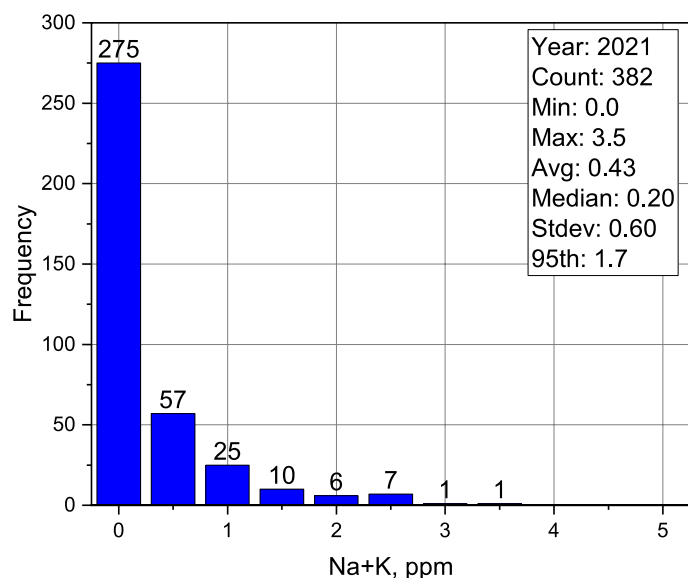


Figure 1. Sodium and potassium content of biodiesel

3.2 Calcium and Magnesium

The Ca+Mg data are shown in Figure 2, with an average of 0.11 ppm, a median of 0.0 ppm, and a 95th percentile of 0.60 ppm.

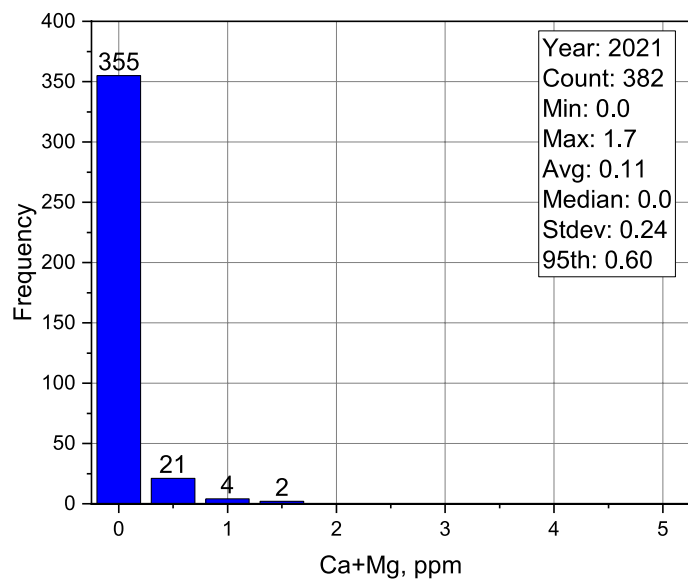


Figure 2. Calcium and magnesium content of biodiesel produced

3.3 Phosphorus

The average phosphorus content was 0.89 ppm (Figure 3). The median value was 0.07 ppm and the 95th percentile was 10 ppm.

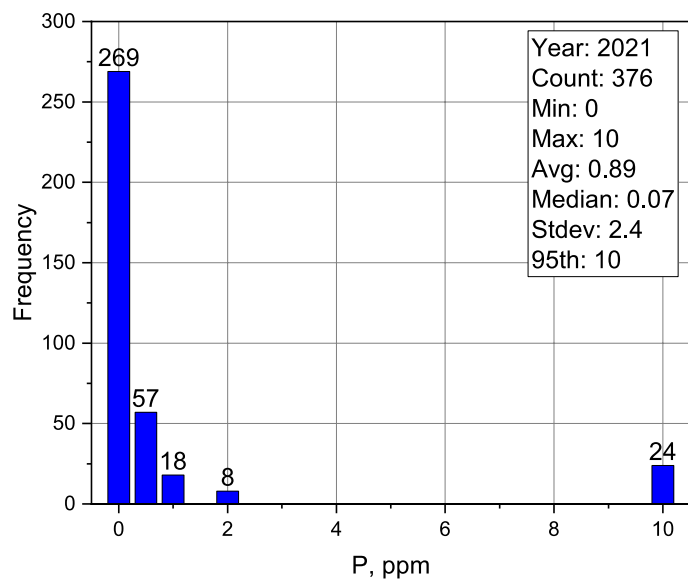


Figure 3. Phosphorus content of biodiesel

3.4 Alcohol Control and Flash Point

Figure 4 shows the flash point analysis. Biodiesel produced in 2021 had an average and median flash point of 152°C and a 5th percentile of 103°C. The average and median alcohol content for the samples was 0.11 mass % and the 95th percentile was 0.16 mass % (Figure 5).

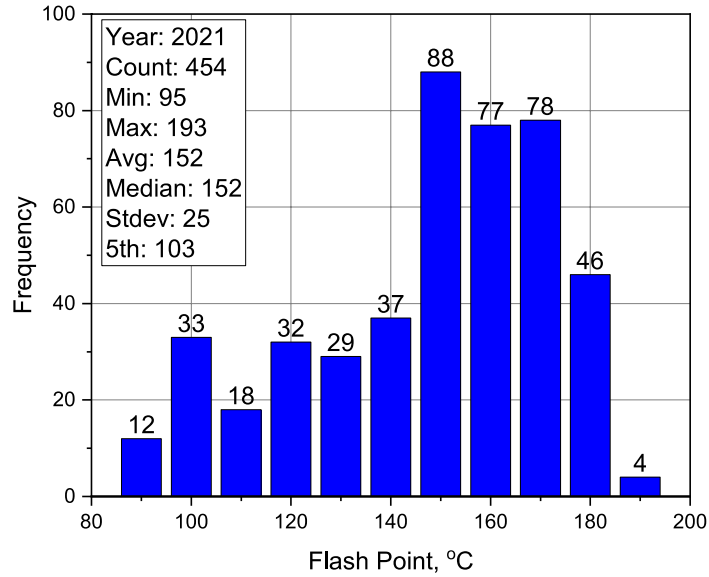


Figure 4. Flash point for biodiesel

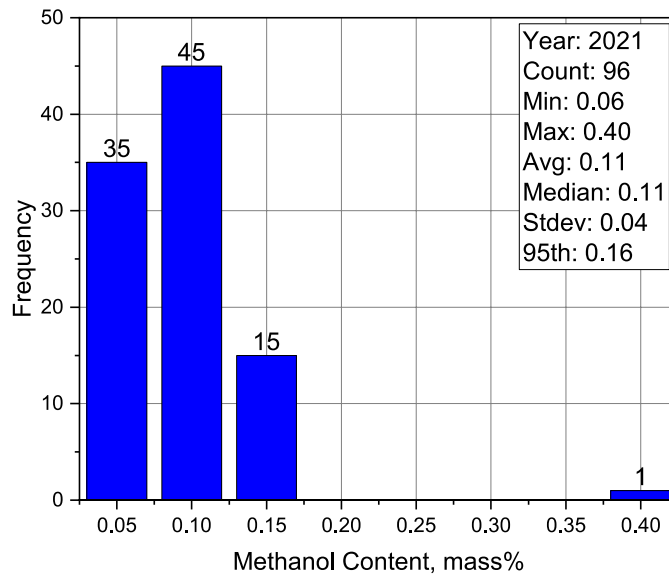


Figure 5. Alcohol content for biodiesel

3.5 Water and Sediment

The results from the water and sediment analysis are shown in Figure 6. The average was 0.001 vol %, the median was 0.000 vol %, and the 95th percentile was 0.010 vol %.

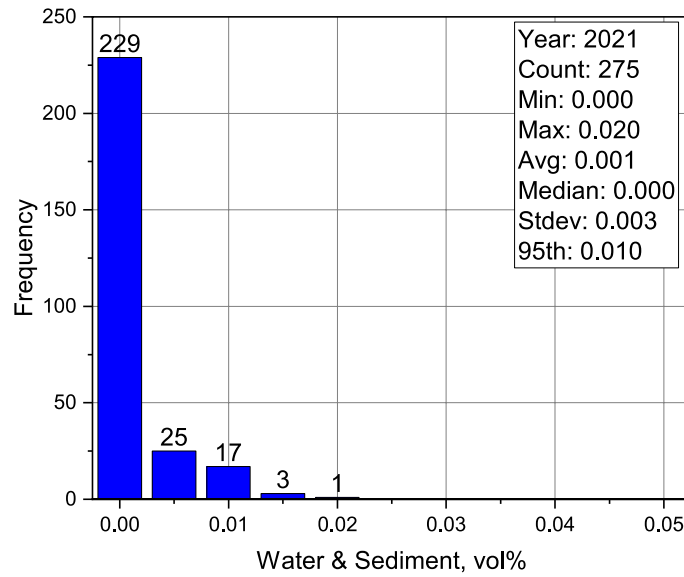


Figure 6. Water and sediment content for biodiesel

3.6 Cloud Point

The cloud point average was 1.6°C, with a median of 0.20°C and a 95th percentile of 9.1°C (Figure 7).

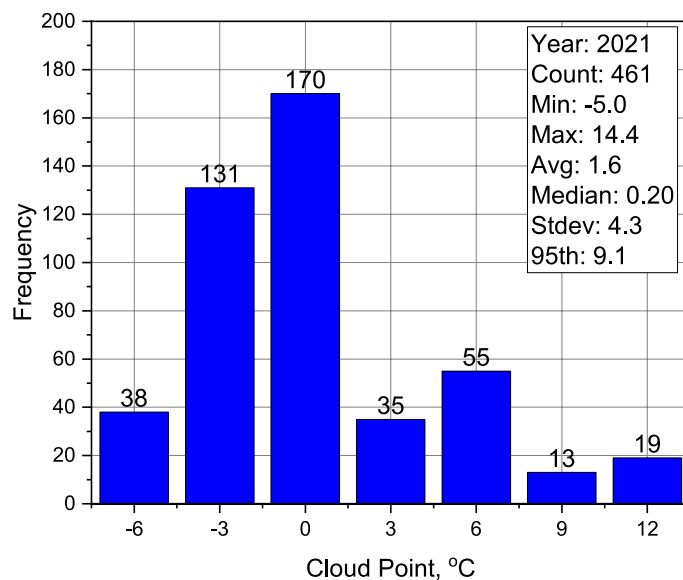


Figure 7. Cloud point results for biodiesel

3.7 Acid Number

Biodiesel in 2021 had average and median acid number results of 0.27 mg KOH/g and the 95th percentile was 0.44 mg KOH/g (Figure 8).

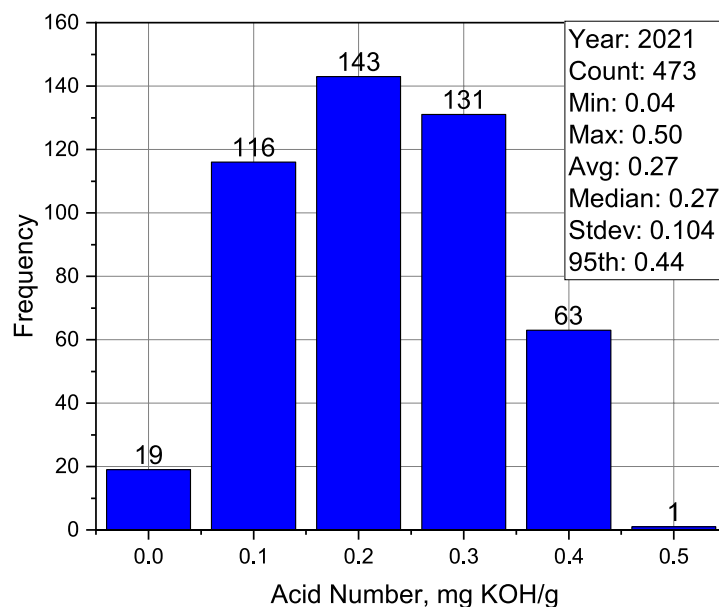


Figure 8. Acid number results for biodiesel

3.8 Free and Total Glycerin

Figure 9 shows the average free glycerin of 0.006 mass %, the median of 0.005 mass %, and the 95th percentile of 0.012 mass %. The total glycerin data are shown in Figure 10. The average was 0.084 mass %, the median was 0.092 mass %, and the 95th percentile was 0.150 mass %.

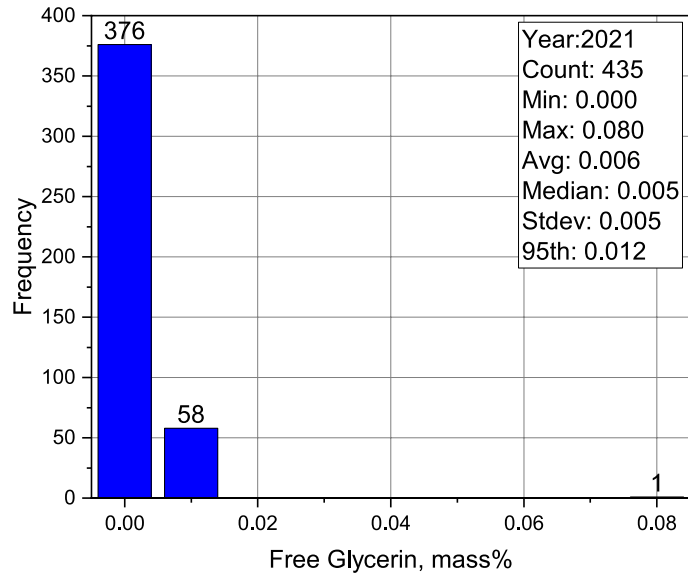


Figure 9. Free glycerin content of biodiesel

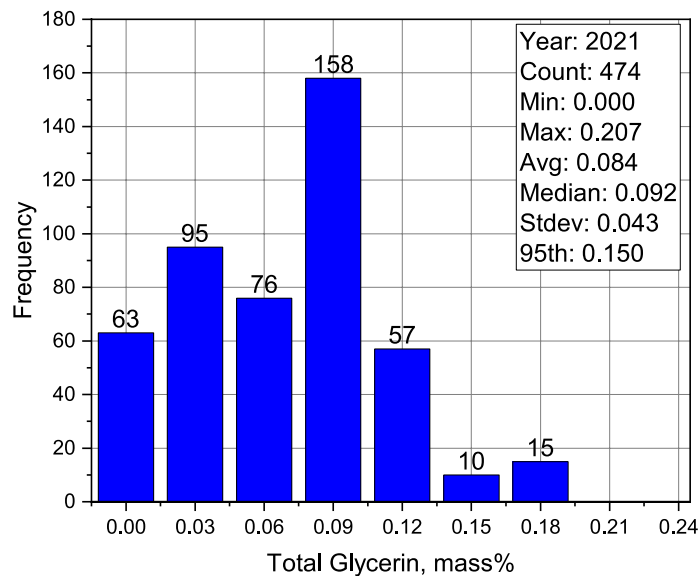


Figure 10. Total glycerin content of biodiesel

3.9 Monoglycerides

Figure 11 shows the distribution of monoglycerides from biodiesel produced in calendar year 2021. The average monoglyceride content was 0.247 mass %, the median was 0.274 mass %, and the 95th percentile was 0.396 mass %.

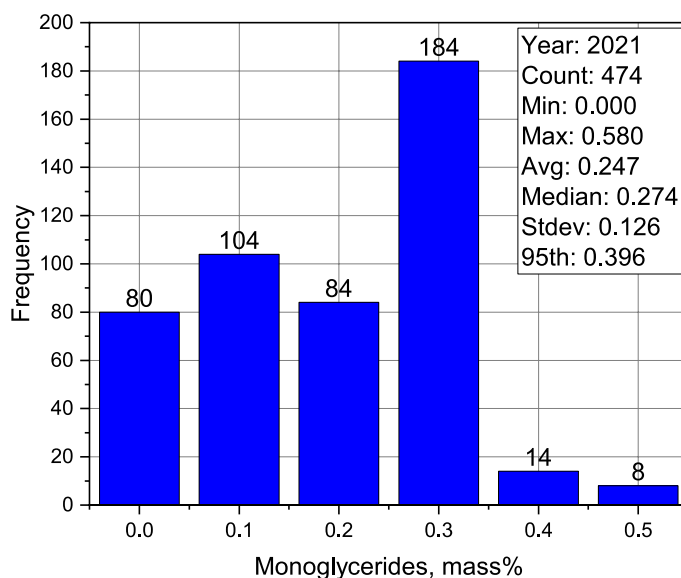


Figure 11. Monoglyceride content of biodiesel

3.10 Sulfur Content

The average sulfur content of biodiesel produced in 2021 was 4 ppm, with a median value of 2.5 ppm and a 95th percentile of 11 ppm (Figure 12).

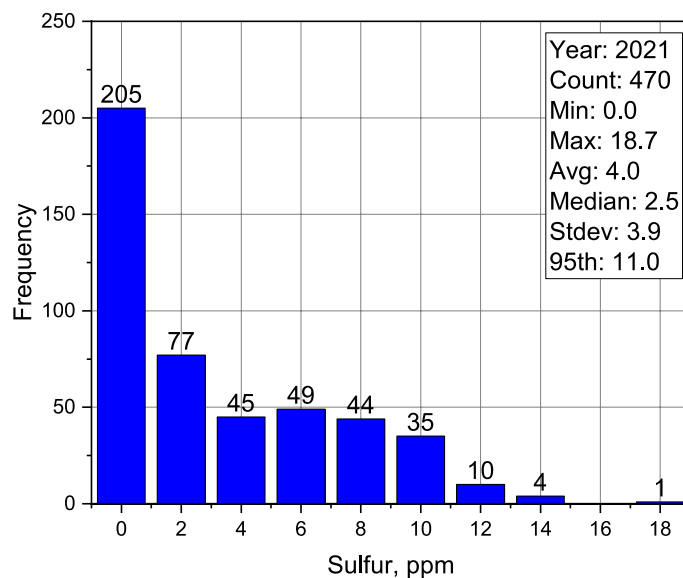


Figure 12. Sulfur content of biodiesel

3.11 Oxidation Stability

The average oxidation stability, shown in Figure 13, was 9.4 hours with a median of 9.0 hours. The 5th percentile for these samples was 5.5 hours.

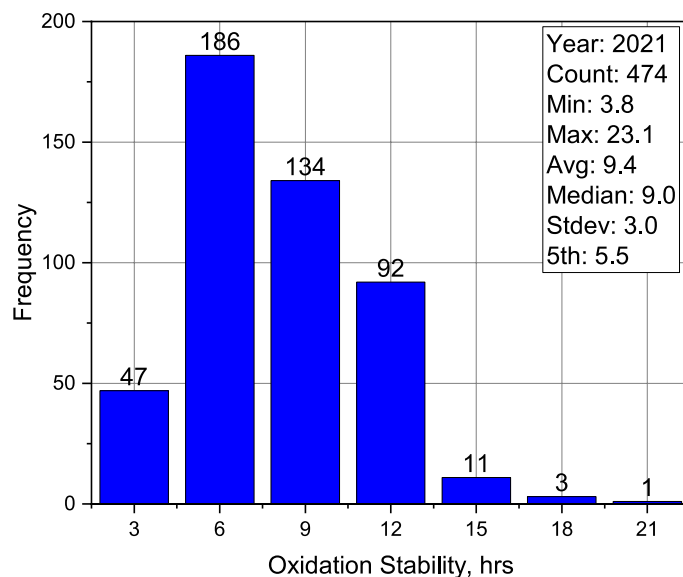


Figure 13. Oxidation stability results for biodiesel

3.12 Cold Soak Filterability Test

Biodiesel produced in 2021 had an average cold soak filterability test result of 110 seconds, a median of 104 seconds, and a 95th percentile of 168 seconds.

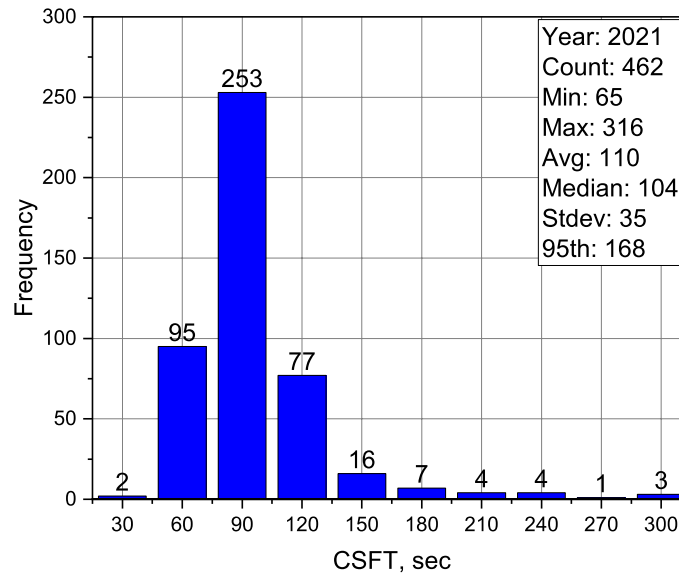


Figure 14. CSFT results for biodiesel

4 Summary

We analyzed monthly quality data voluntarily provided by BQ-9000 biodiesel producers in the United States and Canada for calendar year 2021. This is the fifth in a series of reports on the subject. Monthly quality data were submitted to a third-party team that removed any identifying company information and randomized the data before providing 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.

Table 1. Summary of BQ-9000 Critical Parameters, Calendar Year 2021

BQ-9000 Parameter	Minimum	Maximum	Average	Median	95th Percentile
Na+K, ppm	0	3.5	0.43	0.20	1.7
Ca+Mg, ppm	0	1.7	0.11	0.00	0.60
P, ppm	0	10	0.9	0.07	10
Flash point, °C	95	193	152	158	103 ^a
Alcohol control, mass %	0.06	0.40	0.11	0.11	0.16
Water and sediment, vol %	0.00	0.020	0.001	0.000	0.010
Cloud point, °C	-5	14	1.6	0.25	9.1
Acid number, mg KOH/g	0.04	0.50	0.27	0.27	0.44
Free glycerin, mass %	0.000	0.080	0.006	0.005	0.012
Total glycerin, mass %	0.000	0.207	0.084	0.092	0.150
Monoglycerides, mass %	0.000	0.580	0.247	0.274	0.396
Sulfur, ppm	0	18.7	4	2.5	11
Oxidation stability, h	3.8	23.1	9.4	9.0	5.5 ^a
CSFT, sec	58	316	110	104	168

^a Data for 5th percentile

References

Alleman, T.L. 2020a. *Assessment of BQ-9000 Biodiesel Properties for 2017*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5400-75795.
<https://www.nrel.gov/docs/fy20osti/75795.pdf>.

Alleman, T.L. 2020b. *Assessment of BQ-9000 Biodiesel Properties for 2018*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5400-75796.
<https://www.nrel.gov/fy20osti/75796.pdf>.

Alleman, T.L. 2020c. *Assessment of BQ-9000 Biodiesel Properties for 2019*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5400-76840.
<https://www.nrel.gov/docs/fy20osti/76480.pdf>.

Alleman, T.L. 2021. *Assessment of BQ-9000 Biodiesel Properties for 2020*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5400-79815.
<https://www.nrel.gov/docs/fy21osti/79815.pdf>.

ASTM International (ASTM). 2020. *ASTM D6751-20a, Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels*. West Conshohocken, PA: ASTM International. <http://doi.org/10.1520/D6751-20A>.

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 2021. Due to the nonstandard treatment of the data, no statistical analysis of appendix data was performed.

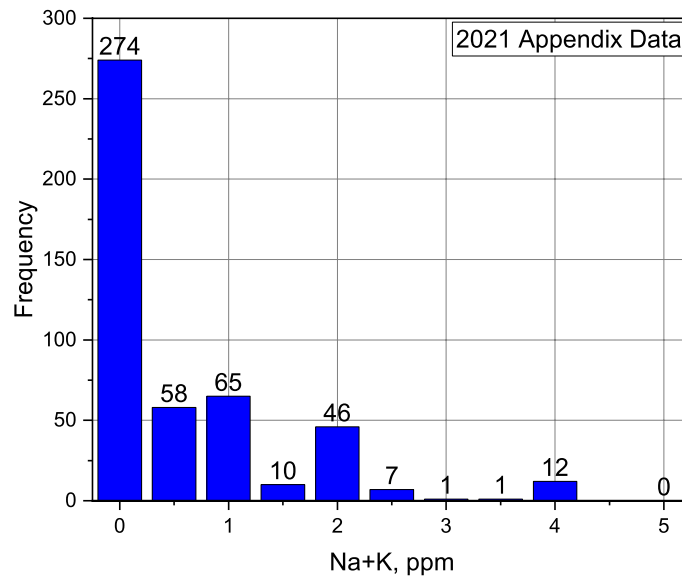


Figure A-1. All data analysis of sodium and potassium content of biodiesel.

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

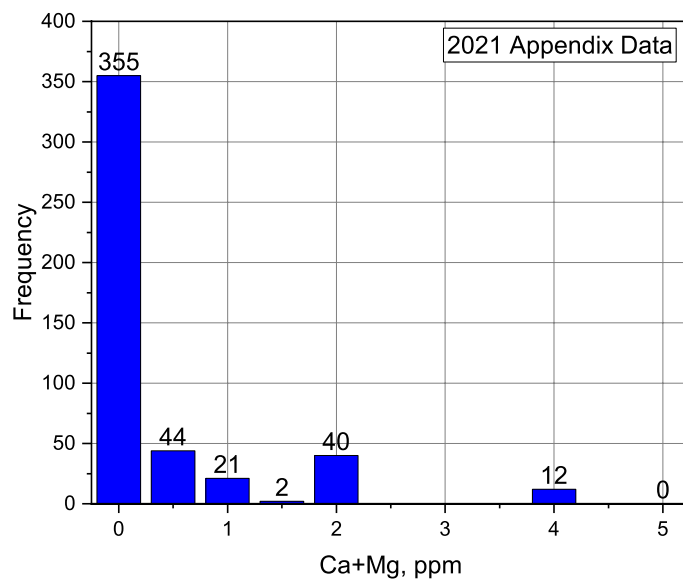


Figure A-2. All data analysis of calcium and magnesium content of biodiesel.

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

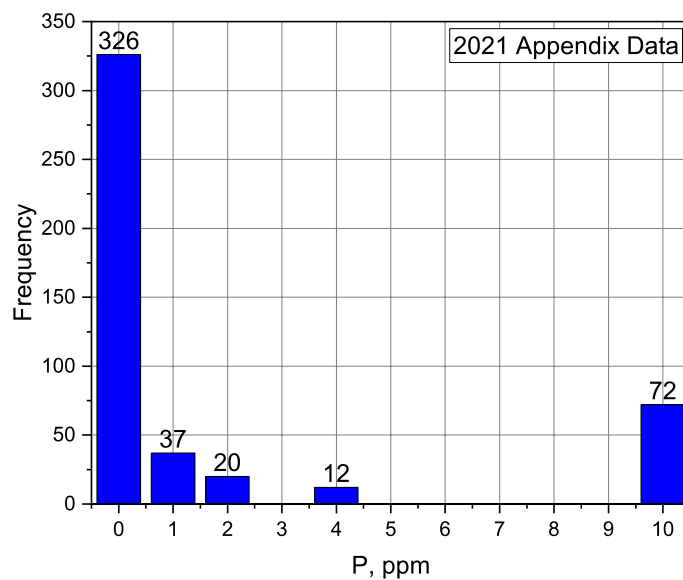


Figure A-3. All data analysis of phosphorus content of biodiesel.

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

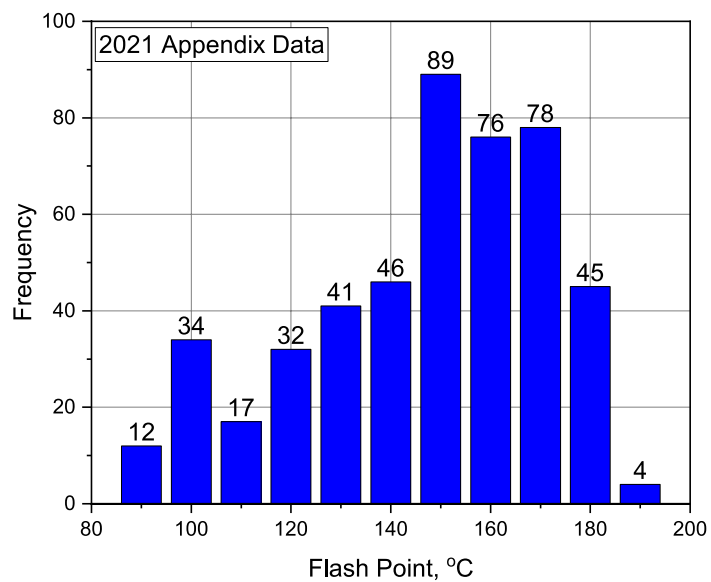


Figure A-4. All data analysis of flash point of biodiesel.

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

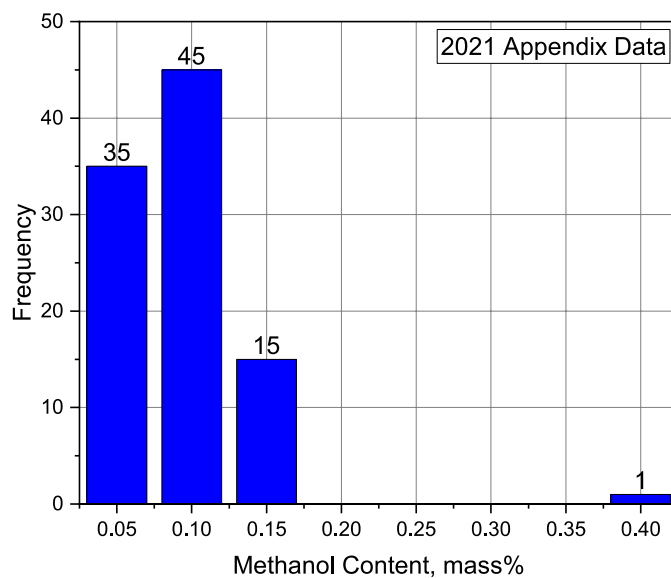


Figure A-5. All data analysis of alcohol control of biodiesel.

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

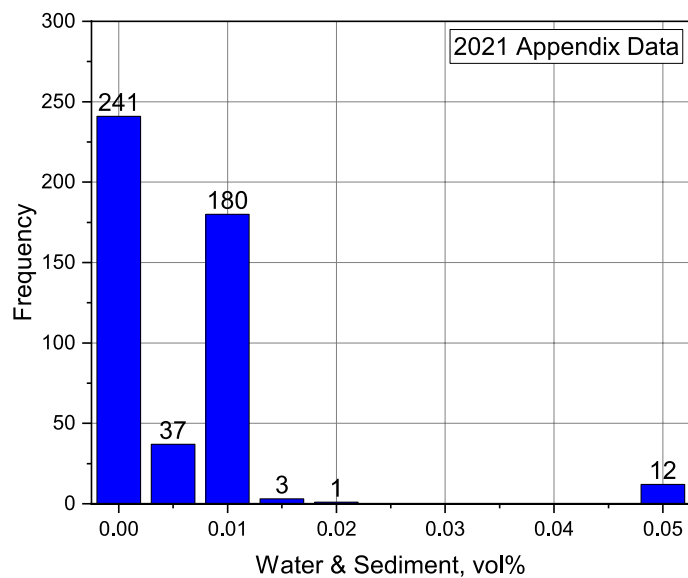


Figure A-6. All data analysis of water and sediment content of biodiesel.
 Data reported as “greater than X” or “less than X” were assumed to have a value of X

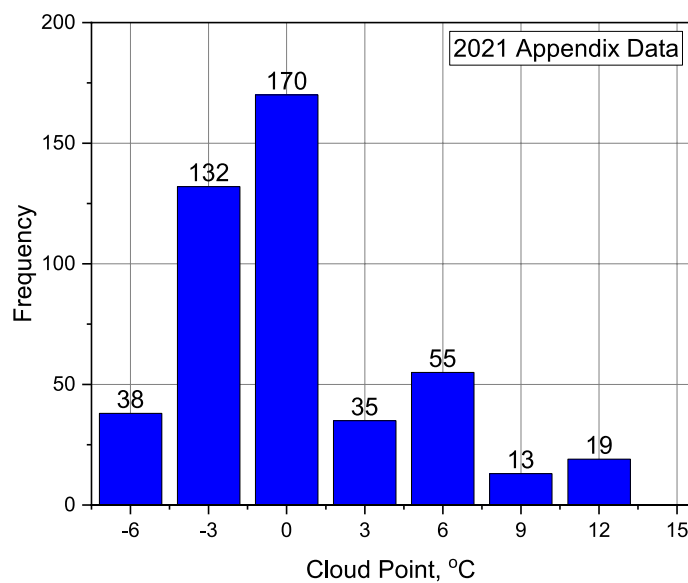


Figure A-7. All data analysis of cloud point of biodiesel.
 Data reported as “greater than X” or “less than X” were assumed to have a value of X

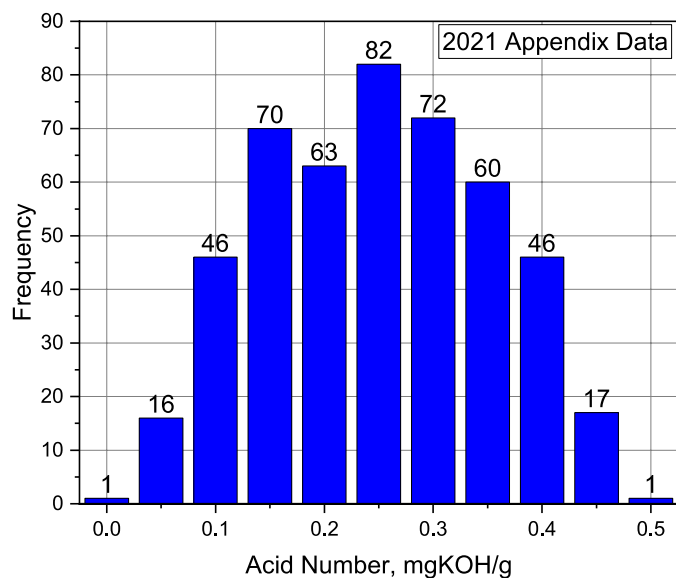


Figure A-8. All data analysis of acid number of biodiesel.

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

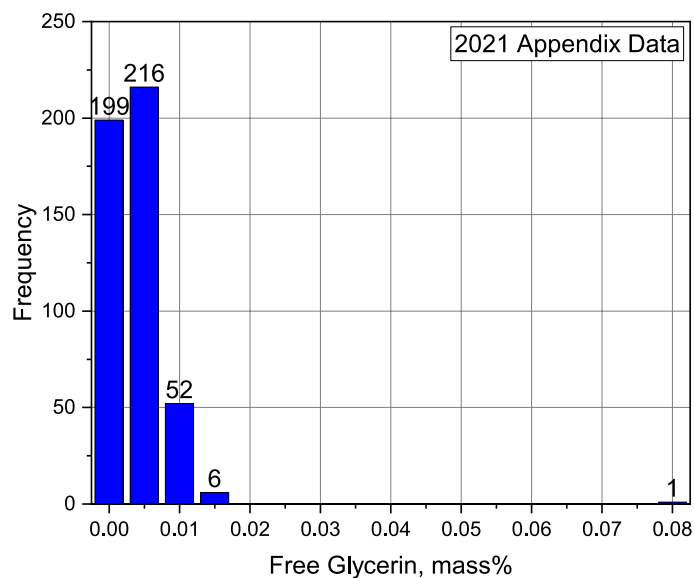


Figure A-9. All data analysis of free glycerin content of biodiesel.

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

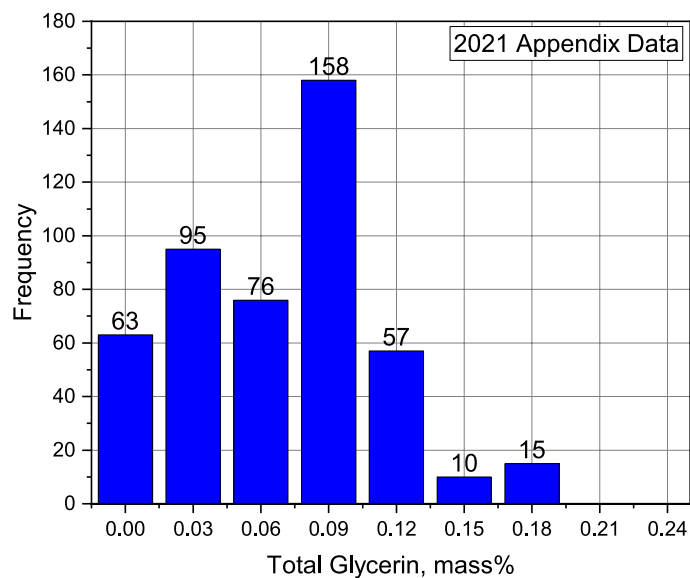


Figure A-10. All data analysis of total glycerin content of biodiesel.

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

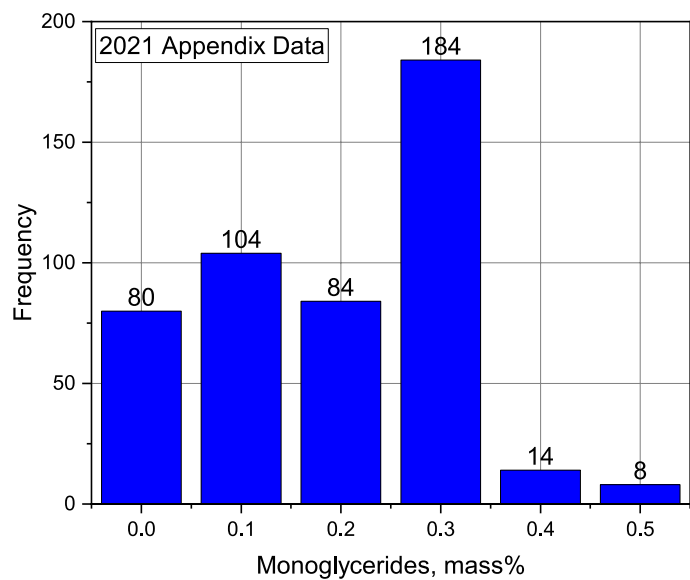


Figure A-11. All data analysis of monoglyceride content of biodiesel.

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

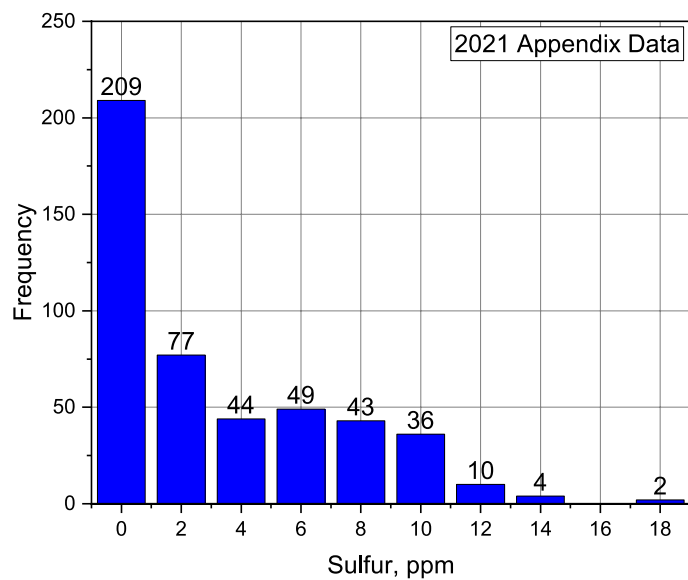


Figure A-12. All data analysis of sulfur content of biodiesel.

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

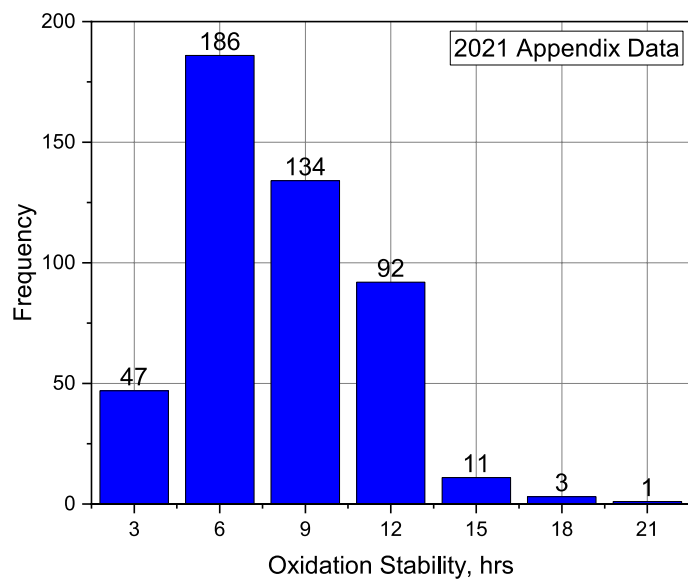


Figure A-13. All data analysis of oxidation stability of biodiesel.

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

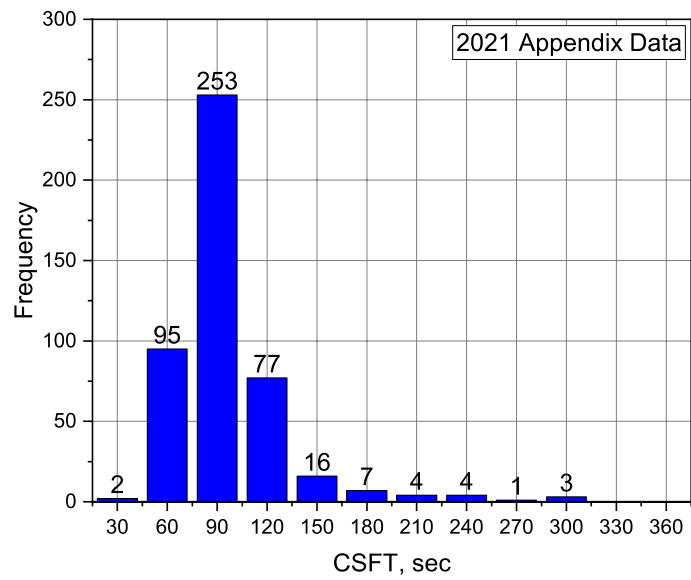


Figure A-14. All data analysis of CSFT of biodiesel.

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