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13. ABSTRACT (Maximum 200 words) The objective of the project was to study the efficacy of using bio-based lubricant and grease technologies in railroad applications (locomotives and maintenance of way equipment). Several commercially available rail curve greases were identified and tested. Three mineral oil-based and three bio-based rail curve greases were selected for comparative testing. Greases included a summer and a winter version. Testing was conducted in an environmental chamber using two grease dispensers from two Original Equipment Manufacturers (OEMs) at different temperatures. Field testing was conducted at two different sites on a revenue service railroad.			
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1 foot (ft)	=	30 centimeters (cm)	1 centimeter (cm)	=	0.4 inch (in)
1 yard (yd)	=	0.9 meter (m)	1 meter (m)	=	3.3 feet (ft)
1 mile (mi)	=	1.6 kilometers (km)	1 meter (m)	=	1.1 yards (yd)
			1 kilometer (km)	=	0.6 mile (mi)
AREA (APPROXIMATE)			**AREA (APPROXIMATE)**		
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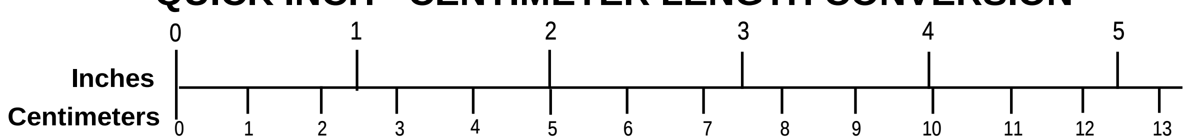
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)	1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)	1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)	10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)			
MASS - WEIGHT (APPROXIMATE)			**MASS - WEIGHT (APPROXIMATE)**		
1 ounce (oz)	=	28 grams (gm)	1 gram (gm)	=	0.036 ounce (oz)
1 pound (lb)	=	0.45 kilogram (kg)	1 kilogram (kg)	=	2.2 pounds (lb)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)	1 tonne (t)	=	1,000 kilograms (kg)
				=	1.1 short tons
VOLUME (APPROXIMATE)			**VOLUME (APPROXIMATE)**		
1 teaspoon (tsp)	=	5 milliliters (ml)	1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 tablespoon (tbsp)	=	15 milliliters (ml)	1 liter (l)	=	2.1 pints (pt)
1 fluid ounce (fl oz)	=	30 milliliters (ml)	1 liter (l)	=	1.06 quarts (qt)
1 cup (c)	=	0.24 liter (l)	1 liter (l)	=	0.26 gallon (gal)
1 pint (pt)	=	0.47 liter (l)			
1 quart (qt)	=	0.96 liter (l)			
1 gallon (gal)	=	3.8 liters (l)			
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)	1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)	1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)
TEMPERATURE (EXACT)			**TEMPERATURE (EXACT)**		
[(x-32)(5/9)] °F	=	y °C	[(9/5) y + 32] °C	=	x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



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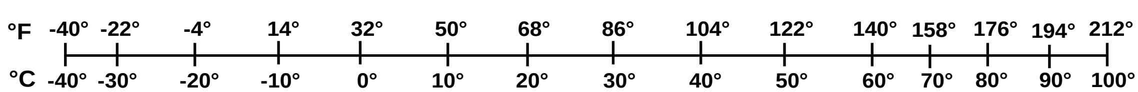

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Executive Summary

Lubricants and greases used in rail equipment can come from biodegradable sources that may be renewable, cost effective, and environmentally benign. This project investigates the feasibility of using readily available biodegradable lubricants and greases in maintenance of way equipment. The research results indicated that bio-based greases perform as well as mineral oil-based greases, and in some cases more effectively, for friction mitigation on railroad tracks.

The University of Northern Iowa National Ag-Based Lubricant (UNI-NABL) Center performed the research on behalf of FRA, and the activities were divided into three categories: (1) Laboratory testing, (2) Testing in wayside equipment in a temperature-controlled environmental chamber, and (3) Field testing of lubricants in wayside equipment in railroad revenue service.

The research team sought input from members of an advisory committee comprised of lubricant suppliers, original equipment manufacturers (OEMs), and railroad managers. The test greases were selected based on the input from the advisory committee and the requirement that the greases were commercially available and had been on the market for a minimum of 5 years. The team identified three bio-based grease suppliers, two of which were manufacturers and the third one a private label distributor. The mineral oil-based greases were those used by major Class I railroads. One of the candidate greases used by a majority of the railroads was selected as a reference sample in the field tests.

The candidate greases were analyzed in laboratory tests, environmental chambers, and in revenue service tests (field tests on a railroad) to assess their performance. Additionally, a new test method was used to assess the tackiness that would categorize the performance of the greases as suitable for rail lubrication.

The results indicated that bio-based greases perform as well as, and in some cases more effectively than, mineral oil-based greases in reducing friction between the railroad tracks and train wheels and carrying down the track. The results of testing in the environmental chamber indicated that bio-based greases can pump at cold temperatures in the typical grease dispensing equipment used by the railroad industry.

Conclusion

This research included extensive data from the laboratory testing, the tests in a controlled environment in two OEM lubricators, and field tests. Based on the data, the researchers concluded that bio-based rail curve greases performed similarly to mineral oil-based based rail curve greases. In a limited comparative test of biodegradability, the bio-based grease proved to be biodegradable but the mineral oil-based based test grease did not.

A test of bio-based content in the test greases showed that most of the bio-based greases had bio-based material contents that met the United States Department of Agriculture (USDA) content requirement for bio-based labeling. The mineral oil-based based greases showed a small amount of bio-based content equivalent to the fatty acids used in soap formation (i.e., less than 10%) and therefore did not qualify as bio-based.

The current retail or market price for all the greases was about the same, ranging from $4.50 to $5.00 per pound. It is likely that this price is considerably lower for large quantities purchased by large railroads; in that case, the price difference between bio-based and petroleum based products may be even more pronounced. In this study, however, the performance of the bio-based grease matched that of the petroleum based grease. Given performance and price parity, bio-based products would have a slight cost-effectiveness advantage because of the added environmental benefits.

Proposed Future Research

Future research should also determine the fuel saving benefits of lubricating railroad tracks—both the curves and the tangent tracks. Bio-based greases can potentially be used more widely on all curves and some tangent tracks if their environmental impact is shown to be minimal. As the cost of fuel continues to rise, the benefit of track lubrication and friction management will become more significant. Tests to measure the fuel savings can be performed in controlled test facilities such as the Transportation Technology Center (TTC), or over an extended period of time on a revenue service railroad.

1. Introduction

The objective of the project was to study the use of bio-based lubricant and grease technologies in railroad applications. Several commercially available rail curve greases were identified and tested. Three mineral oil-based and three bio-based rail curve greases were selected for comparative testing. Greases included summer and winter versions. Testing was conducted in an environmental chamber using two grease dispensers from two OEMs at different temperatures. The researchers also conducted field testing at two different sites on a revenue service railroad. This final report offers all the available data compiled from the tests, along with additional data from a new test method devised to test grease tackiness. This new method was developed by UNI-NABL to determine the cohesiveness and adhesiveness of greases and lubricant; the method is further discussed in subsequent sections of this report and the data obtained is provided in Appendix A.

1.1 Background

This study, mandated in Section 405 of the Passenger Rail Investment and Improvement Act, 2008, required the Secretary of Transportation to investigate the potential use of biodegradable lubricants for railway equipment and report the results of that investigation.

1.2 Objectives

The project aimed to evaluate the feasibility of using readily biodegradable lubricant and greases in railroad equipment through the following:

- Analysis of the potential use of soy-based grease and soy-based hydraulic fluids to perform according to railroad industry standards;
- Analysis of the potential use of *other* readily biodegradable lubricants and greases to perform according to railroad industry standards;
- Comparison of the health and safety of petroleum-based lubricants with readily biodegradable lubricants and grease;
- Comparison of the environmental impact of petroleum-based lubricants with readily biodegradable lubricants and greases;
- A comparison of the performance of readily biodegradable lubricants and greases with that of petroleum-based lubricants; and
- A study of the effects of the readily biodegradable lubricants and greases on railroad equipment components in comparison to the effects of petroleum-based lubricants.

1.3 Overall Approach

In this project, UNI-NABL not only tested soybean oil based greases, but also tested two bio-based greases from other manufacturers. There are no universally accepted standards for rail curve greases. Other industries use the National Lubricating Grease Institute (NLGI) standard “LB-GC” for grease used in automotive bearings and SAE “10W-30,” a standard designed for engine oils. Despite this lack of a universal standard, some companies have been providing greases deemed acceptable by one or more railroads. Although there have been attempts by different groups in Europe to establish basic requirements for railroad greases, these efforts have not been wholly successful.

Because rail curve greases in the United States are mostly for heavy freight loads requiring different properties, the overall approach to assess the effectiveness of the bio-based greases to perform well in the railroad environment was to compare commercially known mineral oil-based and the bio-based greases manufactured and used in the United States. The comparison was comprehensive and included testing in the laboratory, in the temperature controlled environmental chamber, and in the field.

1.4 Scope

This project examined the use of two existing and known grease dispensing pieces of equipment, as well as bio-based greases that had been in commercial use for at least 5 years.

1.5 Organization of the Report

The report is organized into three sections: the test results from the laboratory, the test results from the temperature controlled environmental chamber, and the test results from the field.

2. Rail Curve Grease Properties

There are several established methods for lubricating the railway tracks or wheel flanges. Track lubricant or friction modifier is applied to the *wheel flange, gage face,* or *top of rail*. Friction modifiers are available in several forms, including grease, oil, water, and polymer based mixtures. Solids such as graphite, molybdenum disulfide, solid stick lubricants, pastes, and sprays are also applied to the track or to the wheel flange by various applicators including wayside, on-board [locomotive], hi-rail [on-board of a hi-rail truck], drilled oil galleries in track, as well as hand brush, among others. Figure 1 presents the basic components of a wayside lubricator. The equipment includes a grease reservoir, which is a positive displacement pump that is triggered by a proximity sensor. A control system modulates the duration of the pump's operation based on the number of wheels passing the proximity sensor. Hoses deliver the grease to the rail through wiper bars attached to the gage face of the rail. The wheel flange comes in contact with dispersed grease from the bars. Grease adheres to the flange of the wheel and is distributed along the gage face of the rail through a curve and beyond.

- Wayside lubricator
  - Grease tank/pump
  - Solar Panel/AC
  - Wiper bars clamped inside rails




Figure 1: Basic components of a wayside grease dispenser (lubricator) and grease on gage face

While rail curve grease is simple in concept because it is applied once and then lost to the environment, in practice it requires a multitude of performance attributes that makes it a complex product. Those desired attributes include the following:

1. High extreme pressure property
2. Adequate level of adhesiveness for adherence to the wheel flange and subsequently to the gage face of the track
3. Adequate level of cohesiveness for “carry” down the track and to prevent pump cavitation
4. Good cold temperature flowability in hoses and lines from the reservoir to the distribution bars
5. Adequate flowability within the reservoir for continued flow into the pump inlet at lower grease levels in the reservoir
6. Acceptable anti-rust and anti-corrosion properties
7. Desired level of conductivity so as not to interfere with electrical signals
8. High thin film strength for base oil
9. High viscosity index for base oil
10. High flash and fire point for base oil
11. Biodegradability so as not to persist under the ballasts because that could render the track unstable because of floating

Since the majority of the railway transportation in the United States is for heavy freight transport, rail curve grease use is prevalent. More than 80 percent of the 220,000 miles of tracks are operated by only 5 to 6 Class I railroads.

Each major railroad has its own preferred rail curve grease based on duty cycle and track locations. A Class I railroad can operate along the east coast and carry large volumes of coal. Another Class I may operate on the west coast in dry and mountainous regions of Colorado. Different locations require different performance characteristics from the rail curve grease. Any specification used for freight railroad rail curve grease should include the property specifications of greases currently used by the major railroad companies operating in the United States. Research has shown that properties of the base oil impact the quality of the grease for railroad and other applications. Test methods selected to evaluate the above properties include the following: general properties including worked (60-stroke) and un-worked penetrometer values, dropping point, color, and thickener type.

These properties are often listed in the technical data sheets for most grease and appear in the following tables:

Table 1: General properties

Property	Test Method	Test Description
a. NLGI Grade	Report	
b. Thickener Types	Report	
c. Color	ASTM D156	Standard Test Method for Saybolt Color of Petroleum Products (Saybolt Chromometer Method)
d. Cone Penetration Unworked	ASTM D 217	Standard Test Methods for Cone Penetration of Lubricating Grease
e. Cone Penetration 60X Worked	ASTM D 217	Standard Test Methods for Cone Penetration of Lubricating Grease
f. Dropping Point	ASTM D 2265	Standard Test Method for Dropping Point of Lubricating Grease over Wide Temperature Range
g. Oil Separation	ASTM D 1742	Standard Test Method for Oil Separation from Lubricating Grease during Storage

1. **Testing for extreme pressure property – base oil and grease**
   Perhaps the most important characteristic of rail curve grease is its extreme pressure property. A high extreme pressure property ensures that the grease creates metal-to-metal separation around the curves, thus reducing friction. In addition to measuring the extreme pressure performance, efforts will be made to evaluate various motions including sliding friction, rolling friction, and static friction. For the extreme pressure property, the following tests in Table 2 are recommended:

Table 2: Extreme pressure properties

a. Four Ball Extreme Pressure – grease	ASTM D 2596	Standard Test Method for Measurement of Extreme Pressure Properties of Lubricating Grease (Four-Ball Method)
b. Timken OK Load Test – grease	ASTM D 2509	Standard Test Method for Measurement of Load-Carrying Capacity of Lubricating Grease (Timken Method)
c. Roll Stability	ASTM D 1831	Standard Test Method for Roll Stability of Lubricating Grease
d. Amsler Test		Referenced in literature as an effective evaluative test although it is an old and outdated test (See References)

2. **Testing for adequate levels of adhesiveness and cohesiveness**

   Adhesion and cohesion are two contradictory properties required for the rail curve greases. On one hand, the grease should adhere to the surfaces of the wheel flange and track. On the other hand, the grease must be cohesive enough to be pulled into the pump inlet during the pumping process. Too much cohesiveness could cause stringing and flinging of the grease at high wheel speeds, resulting in a loss of grease and possible buildup under the railcars. These properties are also impacted by changes in temperature. Experience has shown that different tackifiers work better or more poorly at different temperatures. Determining the degree of adhesiveness and cohesiveness would require a multitude of tests, as well as possible testing of the grease in the actual grease dispensing equipment in temperature controlled environments. Possible tests to assess the grease properties are:

Table 3: Tests for adhesion and cohesion

a. Rolling Ball Tack Test	(PSTC) ASTM D3121	Standards set by the Pressure Sensitive Tape Council (PSTC) for tackiness testing of a pressure-sensitive adhesive
b. Apparent Tack of Printing Inks	ASTM D4361	Standard test method for apparent tack of printing inks and vehicles by a three-roller tackmeter
c. Centrifuge Tackiness Tester	Proposed	UNI-NABL Proposed – Separate report provided

3. **Testing for cold temperature flowability**

   The testing for cold temperature performance should include flowability through long lines, as well as slumping in the reservoir. Grease Mobility and Lincoln Ventmeter are two commonly used tests of flowability at changing temperatures. The following standard test methods are proposed:

Table 4: Tests for cold temperature flowability

Grease Mobility -30°C (g/sec:g/min)	U.S. Steel	This would be for the winter version unless the product is considered all-year grease.
Grease Mobility -18°C (g/sec:g/min)	U.S. Steel	This would be for the winter version unless the product is considered all-year grease.
Grease Mobility -10°C (g/sec:g/min)	U.S. Steel	
Grease Mobility 0°C (g/sec:g/min)	U.S. Steel	
Low Temp Torque Test Wheel Bearing	ASTM D4693	Standard Test Method for Low-Temperature Torque of Grease-Lubricated Wheel Bearings
Low Temp Torque Test Ball Bearing	ASTM D1478	Standard Test Method for Low-Temperature Torque of Ball Bearing Grease
Temp Controlled Chamber Test	Appendix C	UNI-NABL Proposed

4. **Oil Separation Property:**
Tests such as the ASTM D1742 "Standard Test Method for Oil Separation from Lubricating Grease during Storage" and ASTM D6184 "Standard Test Method for Oil Separation from Lubricating Grease (Conical Sieve Method)" can be used to determine the oil separation properties of greases. Oil separation may be desirable for certain applications that require the oil to act as a lubricant, but too much bleeding or oil separation could change the consistency of the grease, making it too thick.

Table 5: Tests for oil separation property

Oil Separation	ASTM D1742	Standard Test Method for Oil Separation from Lubricating Grease During Storage
Oil Separation	ASTM D6184	Standard Test Method for Oil Separation from Lubricating Grease (Conical Sieve Method)

5. **Anti-corrosion properties**
As a general rule, it is desirable to determine the corrosion and rust prevention properties of the rail curve grease to ensure the additive compositions are not causing undue rusting or corrosion on the rail surfaces.

Table 6: Tests for corrosion

Corrosion Preventions	ASTM D1743	Standard Test Method to Determine Corrosion Prevention Properties of Lubricating Greases

6. **Testing for conductivity**
   As a general rule, it is desirable to determine the electrical properties of the rail curve grease to ensure that its long term use in the same location does not interfere with switching signals and other electrical systems. The following properties are proposed for consideration and possible inclusion in the specification:

Table 7: Tests for conductivity

Dielectric Constant and Dissipation	ASTM D150 /IEC 60250	May need to be modified for grease
Dielectric Breakdown Voltage and Dielectric Strength	ASTM D149	Standard Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies
Volume Resistivity of Conductive Adhesives	ASTM D2739	Standard Test Method for Volume Resistivity of Conductive Adhesives

7. **Thin film strength – base oil**
   Thin film property can be tested on the base oil to be used in the manufacture of the grease. Table 8 presents the tests proposed for evaluating this property:

Table 8: Tests used to determine thin film strength and other friction and wear properties

Falex Pin and Vee Block	ASTM D3233	Standard Test Methods for Measurement of Extreme Pressure Properties of Fluid Lubricants
Falex Four Ball Wear Test	ASTM D4172	Standard Test Method for Wear Preventive Characteristics of Lubricating Fluid
Fretting Wear Protection	ASTM D4170	Standard Test Method for Fretting Wear Protection by Lubricating Greases

8. **Flash and Fire Points of base oil – ASTM D92 and D93 Flash and Fire Points of base oil**
9. **Pour Point of base oil – ASTM D97**
10. **Viscosity Index of base oil – ASTM D2270**
11. **Other possible properties could include Spreadability and Thermal Resistance**

3. Laboratory Testing and Results

Commercially available mineral oil-based and bio-based greases were identified and acquired for testing. Those greases were known to be commercially available and in use by U.S. railroads. Performing the tests in the same laboratory generates side by side results that provide insight into the performance of these existing products.

Since rail curve greases are made to work with different types of grease dispensing equipment, the commercial greases tested here showed penetrometer values that fell between the NLGI grade numbers. The purpose of this study was to report the results of the penetrometer readings for both summer and winter greases for comparison purposes. The greases' penetrometer values, which represent the "consistency" or thickness of the grease, are often presented in the form of the worked and un-worked values. To work the grease, a known quantity of the test grease is pushed through a disk with standard holes in a standard grease cup. Typically, grease is worked by stroking it 60 times through the orifices of the disk within the standard cup. The "working" of grease is not as applicable to rail curve greases as it is to bearing greases which are exposed to constant shearing. Summer greases in the worked penetrometer readings ranged from 279 to 285 (grade 2), and the winter greases ranged from 305 to 336 (grade 1). Table 9 shows the ranges of penetrometer readings by NLGI.

Table 9: NLGI Grease Consistency Rating

NLGI Grade #	Penetrometer readings after 60 strokes at 25 °C (.1 mm)
000	445-475
00	400-430
0	355-385
1	310-340
2	265-295
3	220-250
4	175-205
5	130-160
6	85-115

The dropping point is an indicator of the melting point temperature of the grease. The summer greases ranged in dropping points from 195.98 °C to 274.6 °C, and the winter greases ranged in dropping points from 196.33 °C to 303.3 °C.

Previous work at the UNI-NABL Center has shown that bio-based greases perform differently when exposed to cold temperatures for an extended period of time. Therefore, the tests of cold temperature, namely the Lincoln Ventmeter and Grease Mobility tests, were performed at different exposure durations and at different temperatures, respectively, than is specified in their standard methods.

Table 10 shows the detailed results of the grease mobility tests. Table 11 shows the detailed results of the Lincoln Ventmeter tests. Table 12 shows side by side results of various tests for all the test greases. The results, presented in Table 12, can be summarized as follows:

1. The penetrometer values indicate that, in general, the summer greases had penetration values between NLGI grades 1 and 2, and the winter greases had penetration values in the range of NLGI Grade 1. While the higher consistency (thicker) winter greases may not perform as well in the extreme cold temperatures, they do perform better when the weather warms up during transition from winter to spring and summer.
2. Dropping Point Test. The dropping point of the grease is an indication of the maximum temperature the grease can maintain before melting. Typically, complex greases have higher dropping points. Dropping points ranged from 195 °C to 303 °C. The majority of bio-based and mineral oil-based greases show dropping points ranging from 195 °C to 205 °C, indicating that bio-based greases are comparable in dropping point to petroleum based greases.
3. The Grease Mobility Test uses a pressure chamber filled with the test grease and then cooled to the desired test temperature. Nitrogen gas pressurized to 150 psi is applied to the chamber and the grease is allowed to flow through a standard orifice for a given period of time. The mass of the grease in grams is reported. Since bio-based greases are known to behave differently when exposed to cold temperature for an extended period of time, this test was modified to keep the test grease at the desired temperature for 24 hours before performing the test. The tests were performed at 0 °C, -8 °C, and -15 °C. Some summer greases failed to flow at -15 °C. In one case, the bio-based #3 summer grease performed better than its winter version (7.51 grams per second flow versus 5.65 grams per second flow). The mineral oil-based grease #3 failed to flow at -15 °C. Since the mineral oil-based grease #2 was used as a reference in the field tests, it is important to note that all bio-based winter greases had more flowability at -15 °C than the mineral oil-based winter grease #2. It should also be noted that cold temperature flowability is often perceived as a shortcoming of bio-based greases. But, the results here indicated that bio-based rail curve greases can match or exceed the performance of mineral oil-based greases in cold temperatures. This is especially significant since the grease was exposed to the -15 °C temperature for 24 hours. Table 10 presents the expanded version of the grease mobility test results.

Table 10: Results of the grease mobility tests

Grease Name	Temp. °C	Sample Mass (g)	Time (s)	Flow (g/sec)	Flow (g/min)
Bio-Based 2 Winter Grease	-15	61.35	122.69	0.5	30
	-8	55.11	56.25	1.02	61.2
	0	107.3	16.53	6.49	389.4
Bio-Based 2 Summer Grease	-15	No Flow	------------	-----------------	-----------------
	-8	50.79	47	1.08	64.84
	0	66.73	10	6.673	400.38
Mineral Oil-Based 2 Winter Grease	-15	47.1	111.22	0.4235	25.409
	-8	48.86	40.72	1.1999	71.994
	0	114.2	16.59	6.8837	413.019
Mineral Oil-Based 2 Summer Grease	-15	52.58	134	0.392	23.54
	-8	53.28	56	0.95	57.08
	0	54.03	17.32	3.11	187.17
Mineral Oil-Based Grease 1 Winter	-15	71.13	69.53	0.9775	58.65
	-8	50.13	14.28	3.511	210.63
	0	84.7	10.54	8.036	482.16
Mineral Oil-Based Grease 1 Summer	-15	41.29	195	0.212	12.72
	-8	52.75	119	0.44	26.59
	0	63.23	77	0.82	49.27
Mineral Oil-Based 1 Cold Temp Grease	-15	50.66	350	0.1447	8.68
	-8	50.44	73	0.691	41.46
	0	49.27	19.38	2.54	152.54
Mineral Oil-Based 3 Winter Grease	-15	51.67	141.84	0.364	21.84
	-8	50.08	64.79	0.773	46.38
	0	48.43	27.9	1.74	104.15
Bio-Based 1 Summer Grease	-15	49.88	6.12	8.15	489.02
	-8	48.13	5.65	8.51	510.6
	0	51.28	3.09	16.59	995.4

Bio-Based 1 Winter Grease	-15	No Flow	------------	-----------------	-----------------
	-8	47.82	61.74	0.775	46.47
	0	47.4	4.22	11.23	673.8
Bio-Based 3 Winter Grease	-15	50.31	11.66	4.31	258.89
	-8	53.83	7.41	7.26	435.87
	0	50.42	3.99	12.64	758.2
Bio-Based 3 Summer Grease	-15	52.65	9.41	5.6	335.71
	-8	51.83	7	7.4	444.26
	0	52.99	3.54	14.97	898.14

4. Water Wash Out. The water washout tests showed a wide range of values. In this test, a standard spray of water at 38 °C (100 °F) is applied to a known mass of grease in a test chamber for a period of time. The lost mass of grease after the test is the percentage of wash-off. The amount of water washout ranged from 1.75 to 28.5 percent for the bio-based and mineral oil-based greases. A test grease which showed 0 percent water wash-off was considered an outlier.
5. Timken Load Test. This test is one of two known test methods used to determine the extreme pressure properties of grease or oils. The other test is the four ball extreme pressure test (see below). Extreme pressure property is one the most important properties for rail curve greases used in the United States because the majority of grease use is for heavy freight revenue service. The Timken test is preferred by some railroads because in this test a flat surface is forced against a rolling bearing race making it a flat-on-round surface that mimics the rolling of wheels over the rail contact. The four ball test uses one ball rolling against three stationary balls, creating round-on-round surface friction. The Timken test results ranged from a low of 27 pounds (lb) to a high of 50 lb. Basically, the bio-based greases and mineral oil-based greases showed similar Timken test results.
6. Four Ball Extreme Pressure Test. In this test, three standard steel balls are locked in a test cup and the test cup is filled with the test medium. A fourth ball is then rotated on the three stationary balls while loaded with weights. Progressively, more weights are added to the fourth ball in each distinct test until the frictional heat causes the balls to weld together; the resulting weight in kilograms (kg) is reported as the weld point. The weld points for all greases ranged from a low of 250 kg in one mineral oil-based grease to a high of 650 kg for one bio-based grease. Coincidentally, the grease with the lowest Timken result showed the highest four ball test result. In general, bio-based greases, because of their high thin film strength of vegetable oils, present a higher extreme pressure property than greases made with mineral oils. Nevertheless, the extreme pressure property of all greases can be improved through the addition of extreme pressure additives.

7. Four Ball Wear Test. This test also uses one rolling ball on three stationary balls locked in a cup filled with the test grease and heated to 75 °C. In this case, the load is 40 kg, but the test is run for 1 hour. The diameters of the scar on the stationary balls are averaged and reported as the scar diameter. This test is more suitable for application where light loads and high speeds are involved and is not necessarily suitable for rail curve grease applications where heavy loads are involved. For anti-wear products, a scar diameter of 0.5 mm or lower is desired. The four ball wear test results for all greases ranged from a low of 0.365 mm to a high of 0.73 mm.
8. Oil Separation Test. Since greases are made from a mixture of soap and lubricating oil, a certain amount of oil can separate from the grease when the grease is left unused for a period of time. Oil separation tests accelerate this process by exposing a known quantity of grease to a standard temperature and pressure and allowing the oil to be sieved out over 24 hours. Since the oil is the actual lubricant, some grease specifications require a degree of oil separation. Because of the variety of dispensing equipment currently in use by railroads, at this time there is no universal specification for degree of oil separation for rail curve greases. Oil separation for the test greases in this study ranged from 0.16 percent to 10.87 percent separation, with both mineral oil-based and bio-based greases having similar oil separation values.
9. Elastomer Compatibility Test. Since bio-based oils are known for their solvency properties, it is important to test their compatibility with elastomers. This test exposes standard rubber test pieces to the test grease for a specified time, then the volume is measured to determine swelling or compaction. It should be noted that products can be mixed to adjust for excessive swelling or excessive contractions. Additionally, a hardness test is performed to determine if the rubber material is softened or hardened. The values for the bio-based and mineral oil-based greases were in the same ranges, with change in volume (ΔV) and change in hardness (ΔH) ranging from a low of 16.48 to a high of 50.13, and hardness values ranging from 7.9 to 16.9.
10. Wheel Bearing Oxidation Test. This test is designed to evaluate the stability of rail greases when used in bearing applications in which the grease is exposed to high heat and shear for extended periods of time (e.g., in the wheel bearing of a rail car). Greases used for track lubrication are not exposed to such conditions. But, the purpose of this test was to report on the oxidation performance of various greases for reference purposes. In this test, a specified quantity of grease is placed in a bearing that sits next to a heating element in a closed chamber. The test instrument measures the starting torque of the motor that drives the bearing. If during the operation the grease thickens up (oxidizes) as a result of heating and shearing, then the torque of the motor increases beyond an acceptable level, typically a percentage of the starting torque, and the test stops. Otherwise, the test is run for 20 hours and then stopped for 4 hours before restarting. A grease that oxidizes and thickens up would require a higher starting torque after each 20 hours, and at some point the starting torque would increase beyond a set value and the test would be terminated. Automotive bearing grease specifications call for a

minimum of 80 hours of runs to pass. Since rail curve greases are not designed with this test in mind, it was not expected that any of these greases would meet the automotive wheel bearing specification. Nevertheless, the comparative data will be useful to determine how bio-based greases and mineral oil-based greases fare in this test. The results ranged from a low of 6.5 hours for one grease to a high of 60 hours for another.

11. Lincoln Ventmeter Test. This test determines the flowability of grease in long hoses and tubes, such as those in the rail curve grease dispensers or the centralized grease dispensers used on semi-trucks. The test requires pumping the test grease into a 25 feet ¼ inch long coiled copper tubing to a pressure of 1,800 psi. Then, the two ends of the tubing are closed with two flow valves, and the tubing is placed in a temperature controller to cool to a desired test temperature for 4 hours. At the end of the temperature exposure, the valve at the end of the tubing is opened to allow the grease to "vent" out of the tubing. If the grease flows out, the pressure drops to zero, indicating that the all 1800 PSI (12,400 kPa) pressure was vented. If the grease is frozen or cannot flow as easily, the pressure drops to a value above zero. Again, since bio-based greases are known to behave differently from mineral oil-based greases when exposed to cold temperatures over extended periods of time, this test was modified to use 24 hours of exposure instead of the test methods specified 4 hours. The test can be run at any temperature, but for this study, the test temperature was set at -18 °C (0 °F). All but one bio-based summer grease vented at this temperature. Some bio-based and mineral oil-based grease vented completely to 1800 PSI (12,400 kPa), while others ranged from a low of 1200 PSI to 1675 PSI. In order to ensure that the bio-based greases would be exposed to the colder temperatures for an extended period of time, the Lincoln Ventmeter was modified to include the grease gun, so that both the grease gun and the ventmeter could be placed in the temperature chamber for repeated testing. Typically, the ventmeter is pressurized by pumping grease into it using a grease gun, then placing the ventmeter in a temperature chamber for 4 hours to cool it to the desired test temperature. In order to improve the process, a grease gun containing the test grease was placed inside the ventmeter coil and the entire assembly was placed in the environment chamber. Figure 2 shows a picture of the modified Lincoln Ventmeter. Table 11 shows a compilation of the results for the 4-hour and 24-hour Lincoln Ventmeter tests.

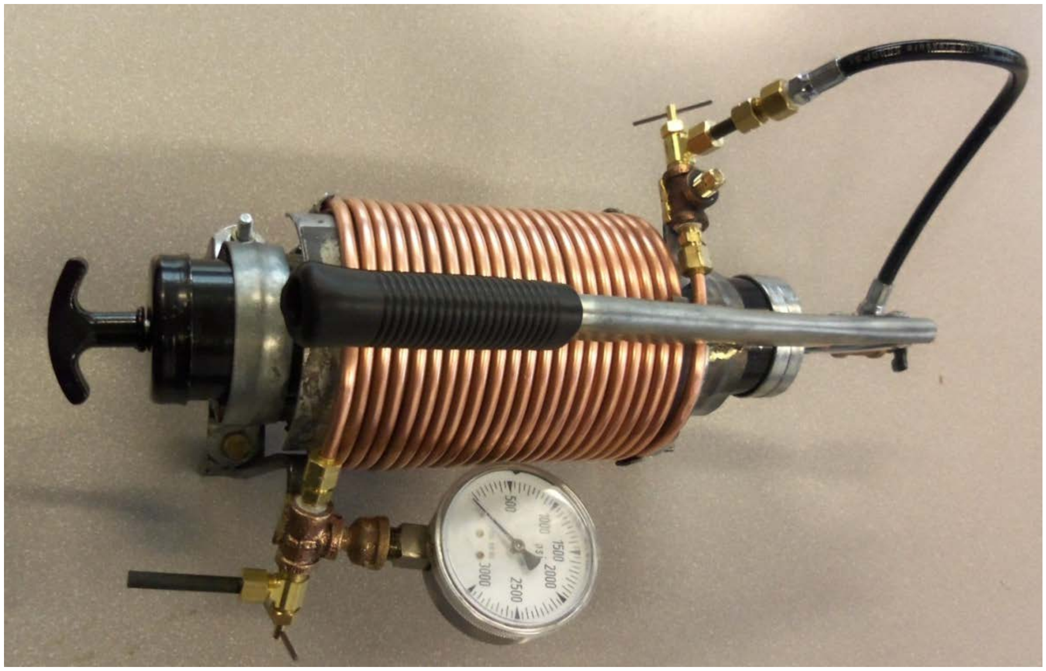


Figure 2: Modified Lincoln Ventmeter with grease gun built inside

Table 11: Results for Lincoln Ventmeter—4-hour and 24-hour test periods

Grease #	Brand	Time	Temp in ?C	1st 30 sec.	2nd 30 sec.	3rd 30 sec.	Ventability	Time	1st 30 sec.	2nd 30 sec.	3rd 30 sec.	Ventability
12-012	Biobased 2 Winter	4 hrs	0	1800	1800	1800	1800	24 hrs	1775	1775	1775	1775
			-8	1750	1750	1750	1733		1750	1750	1750	1750
			-15	1700	1700	1700	1700		1700	1725	1725	1716.6667
12-013	Biobased 2 Summer	4 hrs	0	1800	1800	1800	1800	24 hrs	1800	1800	1800	1800
			-8	1800	1750	1750	1767		1775	1800	1725	1766.6667
			-15	1750	1425	1900	1692		1725	1750	1725	1733.3333
12-014	Mineral Based 2 Summer	4 hrs	0	1800	1800	1800	1800	24 hrs	1800	1800	1800	1800
			-8	1775	1785	1785	1782		1775	1785	1785	1782
			-15	1785	1790	1800	1792		1775	1790	1775	1780
12-015	Mineral Based 2 Winter	4 hrs	0	1750	1725	1750	1742	24 hrs	1725	1725	1725	1725
			-8	1725	1725	1725	1725		1725	1725	1725	1725
			-15				#DIV/0!					#DIV/0!
12-045	Mineral Based 1 Winter	4 hrs	0	1750	1775	1760	1762	24 hrs	1750	1750	1775	1758
			-8	1750	1750	1750	1750		1750	1750	1750	1750
			-15	1750	1750	1760	1753		1490	1675	1650	1605
12-046	Mineral Based 1 Summer	4 hrs	0	1800	1800	1800	1800	24 hrs	1800	1800	1800	1800
			-8	1800	1800	1800	1800		1800	1800	1800	1800
			-15	1800	1800	1800	1800		1800	1800	1800	1800
12-053	Mineral based 1 Cold Temp	4 hrs	0				#DIV/0!	24 hrs				#DIV/0!
			-8				#DIV/0!					#DIV/0!
			-15				#DIV/0!					#DIV/0!
12-061	Mineral Based 3 Summer	4 hrs	0	1750	1700	1700	1717	24 hrs	1725	1750	1725	1733.3333
			-8	1700	1750	1700	1717		1700	1700	1700	1700
			-15	1725	1775	1700	1733		1700	1700	1700	1700
12-065	Biobased 2 Winter	4 hrs	0	1800	1800	1800	1800	24 hrs	1800	1800	1800	1800
			-8	1800	1800	1800	1800		1800	1800	1800	1800
			-15	1800	1800	1800	1800		1800	1800	1800	1800
12-066	Biobased 2 Summer	4 hrs	0	1750	1750	1750	1750	24 hrs	1750	1750	1750	1750
			-8	1750	1750	1750	1750		1750	1750	1750	1750
			-15	1750	1750	1750	1750		1575	1575	1600	1583
12-067	Biobased 3 Winter 0-100	4 hrs	0	1800	1800	1800	1800	24 hrs	1750	1750	1750	1750
			-8	1750	1750	1750	1750		1750	1700	1750	1733
			-15	1650	1700	1750	1700		1700	1700	1700	1700
12-068	Biobased 3 Summer 35-100	4 hrs	0	1775	1775	1775	1775	24 hrs	1775	1775	1775	1775
			-8	1775	1775	1775	1775		1775	1775	1775	1775
			-15	1775	1775	1775	1775		1425	1425	1675	1508

12. Rust Prevention Test. This test, too, is designed more for bearing and automotive applications than for rail applications, and greases can be formulated to pass this test. Simply described, a bearing is packed with a known quantity of grease and then the assembly is placed in distilled water for a specified period of time. The bearing is then rated pass or fail based on presence of rust. This test was performed on all the greases; none of them passed.

Table 12 presents the data from the aforementioned tests.

Table 12: Test results for the 12 test greases including summer, winter, bio-based, and mineral oil-based greases

	Standard	Bio-Based 2 Winter Grease	Bio-Based 2 Summer Grease	Mineral Oil-Based 2 Winter Grease	Mineral Oil-Based 2 Summer Grease	Mineral Oil-Based Grease 1 Winter	Mineral Oil-Based Grease 1 Summer	Mineral Oil-Based 1 Cold Temp Grease	Mineral Oil-Based 3 Winter Grease	Bio-Based 1 Winter Grease	Bio-Based 1 Summer Grease	Bio-Based 3 Winter Grease	Bio-Based 3 Summer Grease
Test Method		**12-012**	**12-013**	**12-014**	**12-015**	**12-045**	**12-046**	**12-053**	**12-061**	**12-065**	**12-066**	**12-067**	**12-068**
Cone Penetration Un-worked	**ASTM** D 217	290	279	316	316	323	266	303	325	317	293	325	287
Cone Penetration 60X Worked	**ASTM** D 217	294	285	332	314	305	281	297	256	314	281	318	279
Dropping Point (°C)	**ASTM** D 2265	303.3	274.6	212.3	200.6	205.3	204.7	260	249.17	201.34	196.33	200.67	195.98
Grease Mobility -15°C (g/sec:g/min)	U.S. Steel	0.5 : 30.00	No Flow	0.42 : 25.41	.39 : 23.54	.98 : 58.65	0.212 : 12.72	0.145 : 8.68	Fail- no grease output	8.15 : 489.0	Fail- no grease output	5.65 : 338.85	7.51 : 450.69
Grease Mobility -8°C (g/sec:g/min)	U.S. Steel	1.02 : 61.20	1.08 : 64.84	1.20 : 72.00	.95 : 57.08	3.51 : 210.63	0.44 : 26.59	0.69 : 41.46	.773 : 46.38	8.51: 510.6	.775 : 46.47	11.82 : 709.13	12.3 : 737.76
Grease Mobility 0°C (g/sec:g/min)	U.S. Steel	6.49 : 389.40	6.67 : 400.38	6.88 : 413.02	3.11 : 187.17	8.04 : 482.16	0.82 : 49.27	2.54 : 152.54	1.74 : 104.15	16.59 : 995.4	11.23 : 673.8	16.14 : 968.4	18.073 : 1084.38
Water Washout, 100°F	**ASTM** D1264	2.03%	1.75%	14.19%	16.90%	4.90%	28.50%	3.99%	11.23%	9.80%	0.00%	21.95%	12.20%
Timken Load Test	**ASTM** D 2509	40 lb	50 lb	40 lb	35 lb	45 lb	35 lb	45 lb	45 lb	35 lb	27 lb	45 lb	35 lb
Four Ball Extreme Pressure Test	**ASTM** D 2596	400	400	400	400	400	400	400	250	500	620	500	500

Four Ball Wear	**ASTM** D 2266	0.73	0.69	0.56	0.64	0.46	0.418	0.66	0.365	0.45	0.453	0.489	0.4053
Oil Separation	**ASTM** D 1742	0.22%	0.16%	4.03%	7.18%	10.87%	5.16%	5.84%	7.03%	8.50%	1.57%	5.06%	3.14%
Elastomer Compatibility	**ASTM** D 4289	ΔV=45.11% ΔH=-15	ΔV=43.51% ΔH=-16.2	ΔV=51.99% ΔH=-16.7	ΔV=50.13% ΔH=-16.9	ΔV=16.48 ΔH=-7.9	ΔV=26.86% ΔH=-10.6	ΔV=17.73 ΔH=-7.9	ΔV= 22.86 ΔH=-10.7	ΔV= 23.92 ΔH=-10.5	ΔV= 33.99 ΔH=-14.8	ΔV= 32.26 ΔH=-10.6	ΔV= 32.43 ΔH=-13.4
Wheel Bearing	**ASTM** D 3527	38.7 hrs	13.8 hrs/ 25.5 hrs	60.0 hrs	25.9 hrs	20.0 hrs	60.0 hrs	60.0 hrs	20.0 hrs	20.0 hrs	6.5 hrs	15.8 hrs	20 hrs
Ventmeter- Amount vented from 1800 psi/ 30 sec/ -18°C	Lincoln method	1633 psi	1675 psi	1500 psi	1667 psi	1650 psi	1800 psi	1800 psi	1500 psi	1800 psi	0 psi- Fail	1533 psi	1200 psi
Rust Preventative Properties	IP 220 Distilled Water Washout	Fail	Fail	Fail	Fail	Fail	Fail	Pass	Fail	Fail	Fail	Fail	Fail

The above results, when combined with the testing that was performed in the environmental chamber with the grease dispensing equipment and again in the field with the grease dispensing equipment, provide three ways of looking at the comparative performance of bio-based and mineral oil-based greases.

3.1 Test in Temperature Controlled Chamber

The purpose of testing in the environmental chamber was to expose two commercial lubricators from two OEMs to the test greases side by side and perform testing at different temperatures. The test allowed each grease to be tested in the two test lubricators at different temperature points ranging from approximately 110 °F (38 °C) to approximately -10 °F (-23 °C). Table 13 presents the resources, including the grease lubricators, used for this test.

Table 13: Resources and grease used for test of greases in the environmental chamber

Hardware Resources	Test Grease
Environmental Chamber	Petroleum based grease summer grease #2
	Petroleum based winter grease #2
OEM 1 Lubricator (Portec)	Bio-based summer grease #1
Train Simulator (digital)	Bio-based winter grease #1
Output hose and single bar	Bio-based summer grease #2
	Bio-based winter grease #2
OEM 2 Lubricator (Lincoln)	Bio-based summer grease #3
Output system and single bar	Bio-based winter grease #3
**25 pails of each grease were acquired	

The equipment included a wayside lubricator with digital control box, supply hose, and one 48-Port bar. Simultaneously, a second wayside lubricator equipped with digital control box, supply hose, and bar was tested. Train traffic was simulated using a train simulator. The distribution bars for each lubricator were placed in a plastic lined drum to catch the grease being pumped through the bars.

The two lubricators were placed in the environmental chamber and subjected to different temperatures. Prior to starting each test at the given temperature, each lubricator was filled with 9 pails (315 lb) of the grease to be tested. At each test temperature, both lubricators were filled with the exact same grease. The grease was then leveled in the tank and a measurement taken for the height of the grease in the reservoir. At each temperature set point, the grease was allowed to acclimate for 24 hours before testing commenced. The test greases were evaluated at the following temperatures:

a. 37.8 °C (100 °F)
b. 50 °C (50 °F)
c. 0 °C (32 °F)
d. -17.8 °C (0 °F)

e. -23.3 °C (-10 °F)

** After the 24-hour acclimation period, the un-worked penetration for each grease was measured at each designated temperature.

Because a quantity of grease was lost from each prior test temperature, the grease lost (pumped out from prior test) was weighed and an equal amount of new grease was added to each lubricator to maintain consistency in testing procedures. The newly combined grease was then allowed to acclimate to the desired test temperature. The same grease was tested in both lubricators.

The digital train simulator was programmed to simulate 25 car trains with 60-foot truck centers running at 5 miles per hour (mph). After each train, the system was shut down for 1 minute before the next start. It is estimated that approximately 0.8 lb of grease should be pumped for every 100 axels passing the wheel sensor (two lubricating bars – one on each side of the track). The goal was to program each lubricator in a way that ensured 0.4 lb of grease would be pumped for every 100 axels since only one lubricating bar was being used. The same simulation was run at each temperature.

The test results showed that the lubricator from OEM1 unit set to pump for 0.35 seconds every 5 axles outputted 0.3778 lb of NLGI grade 1 grease at 100 °F during one train pass using the simulator. The OEM 2 lubricator unit was set to pump for 3.5 seconds on every axle. The settings on the OEM 2 unit were such because a relay is used to simulate a wheel count every time the OEM 1 unit's pump engages. The test results also showed that the settings on the OEM 2 unit output 0.3908 lb at the same conditions above. The output for each lubricator was similar in like conditions and was close to a desirable 0.8 lb per 100 wheels (figuring one bar system should be half of that).

Since each test started at the highest test temperature, after each test at each temperature, the environmental chamber was cooled to the next lower temperature and the grease allowed to acclimate for a minimum of 24 hr.

3.1.1 Measurements

The measurements recorded for each individual test grease during the environmental chamber tests are:

a. Total grease pumped per temperature (lb)

b. Adherence of grease to steel (manual/visual)

c. Funneling/cavitation. A measurement was taken at the highest and lowest point in the reservoir once each test run was completed. This was also considered a measure of slump-ability and a way to show any funnel formation towards the pump inlet.

d. Unworked penetration of grease at each acclimated temperature (1/10s millimeter)

A severe reduction in grease output is considered an indication of pump cavitation. In which case, output grease would be examined for air pockets. Figures 3 through 6 show the arrangement of the two OEM lubricators in the environmental chamber, the quantity and position of grease in the reservoirs, and the position of grease dispensing bars in metal drums.

Figure 3: The test grease dispensers from two OEMs

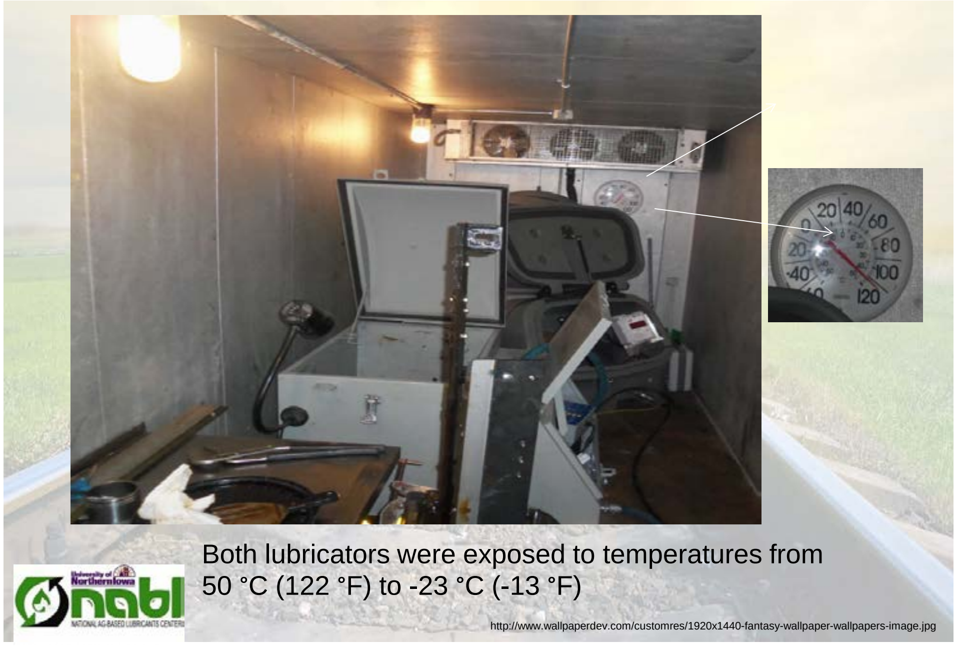


Figure 4: Arrangement of test grease dispensers and dispensing bars in the environmental chamber

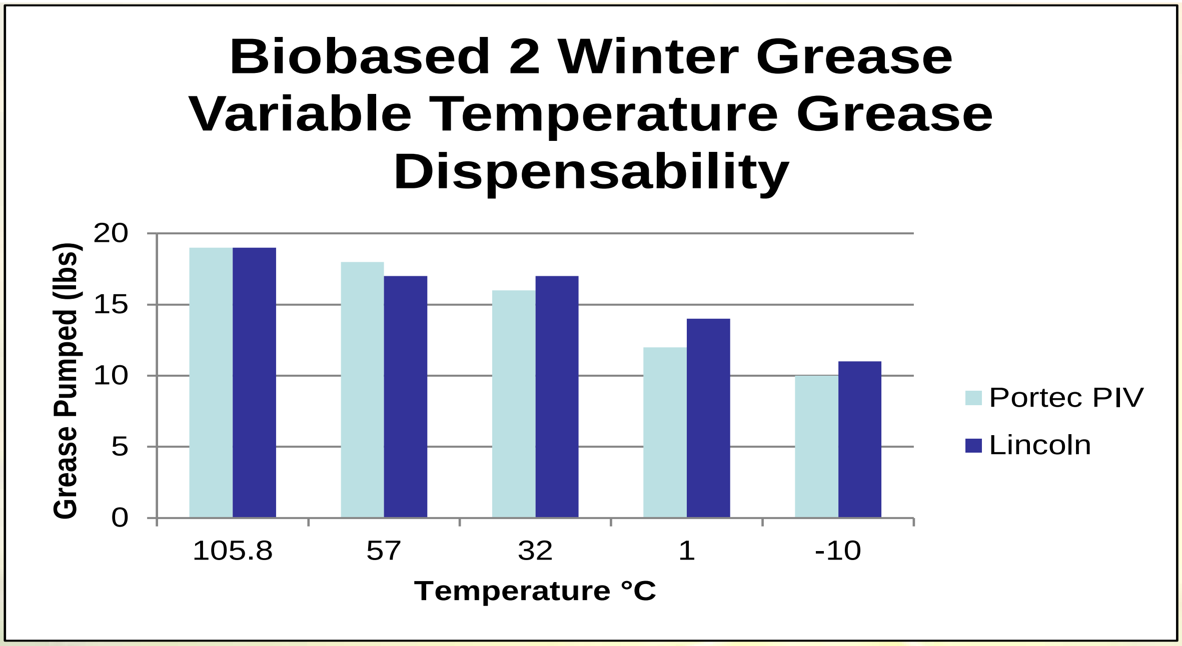
Figure 5: Placement of test grease in reservoirs to allow for observation of funneling and slumping

Figure 6: The test grease dispenser bars and collection methods for the pumped grease

3.1.2 Results

The following charts present the amount of grease pumped by each lubricator with fixed settings at different temperatures; the charts also show the un-worked penetrometer value of each grease after it was tested and then acclimated to the test temperature.

Figures 7 and 8 present the amount of grease dispensed and the penetrometer values at various test temperaures. In Figure 7, the winter version of one bio-based grease was pumped equally by both dispensers. By contrast, the summer version in Figure 8 showed that one dispenser (Lincoln) pumped less than the second one (Portec) at hight temperatures, but its output increased at colder temperatures.



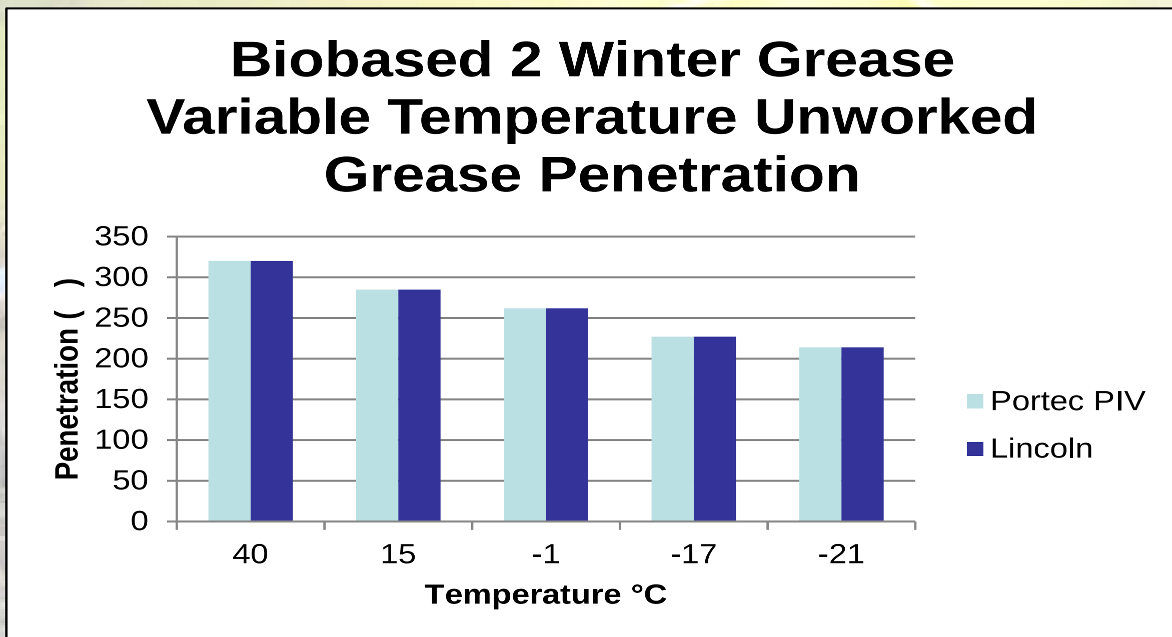


Figure 7: Amount of grease dispensed through each lubricator & penetrometer values at various test temperatures for Bio-Based Winter Grease 2

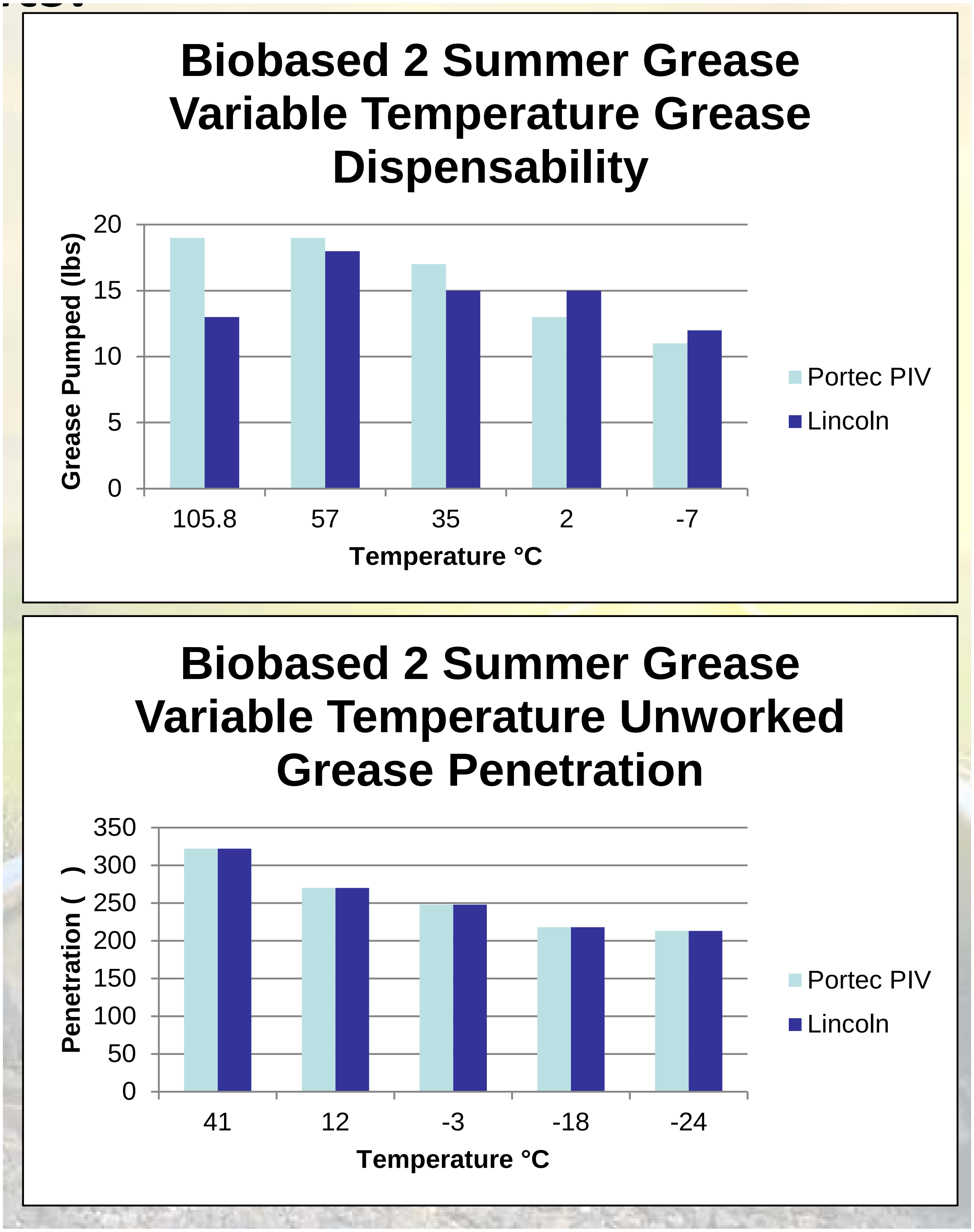


Figure 8: Amount of grease dispensed through each lubricator & penetrometer values at various test temperatures for Bio-Based Summer Grease 2

Figures 9 and 10 present the amount of grease dispensed and the penetrometer values at various test temperaures. In Figure 9, the summer version of one bio-based grease was pumped equally by both dispensers. But the winter version in Figure 10 showed that one dispenser (Lincoln) pumped less than the second one (Portec) at high temperatures; however, its output increased at colder temperatures to equal the output of the other lubricator.

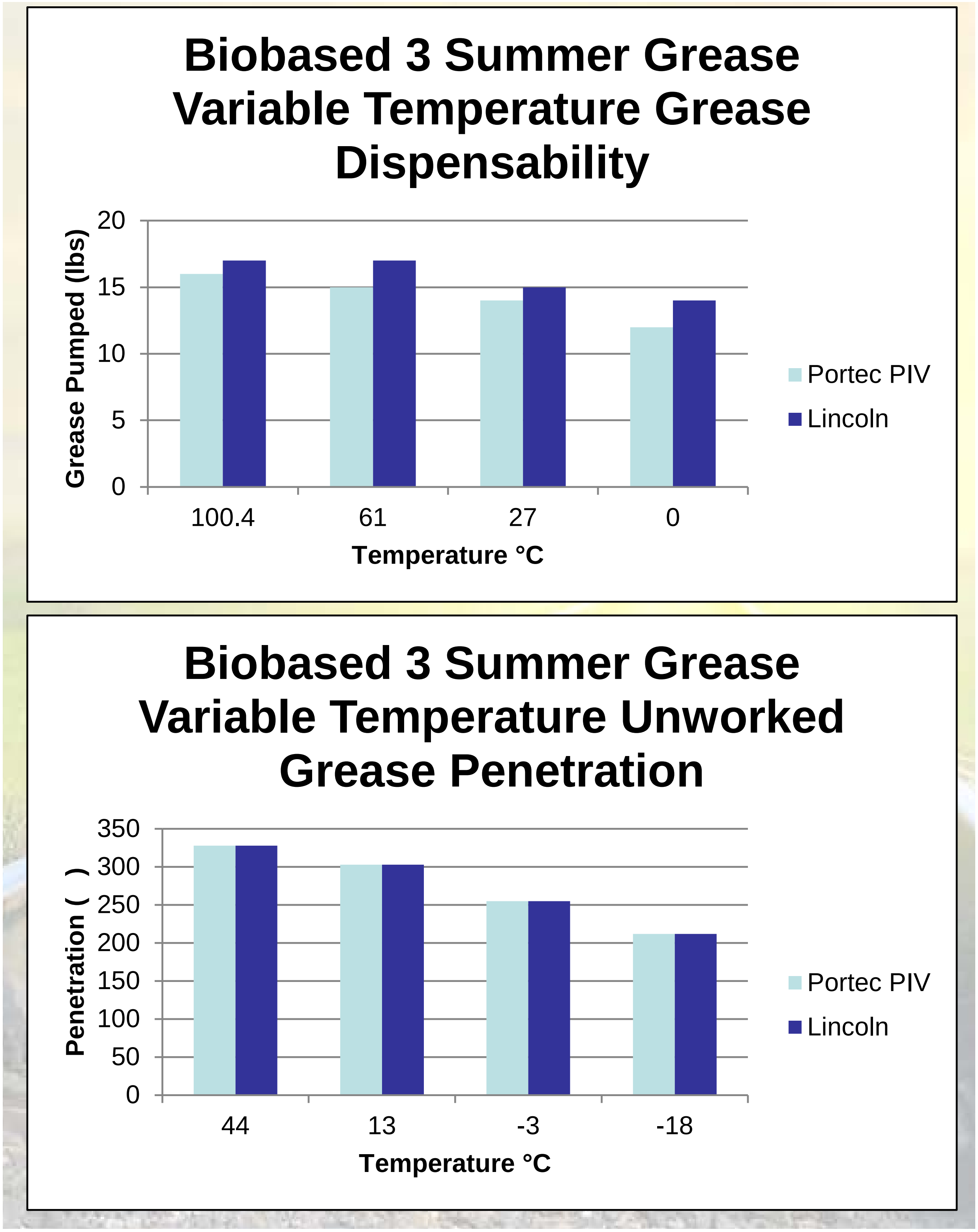
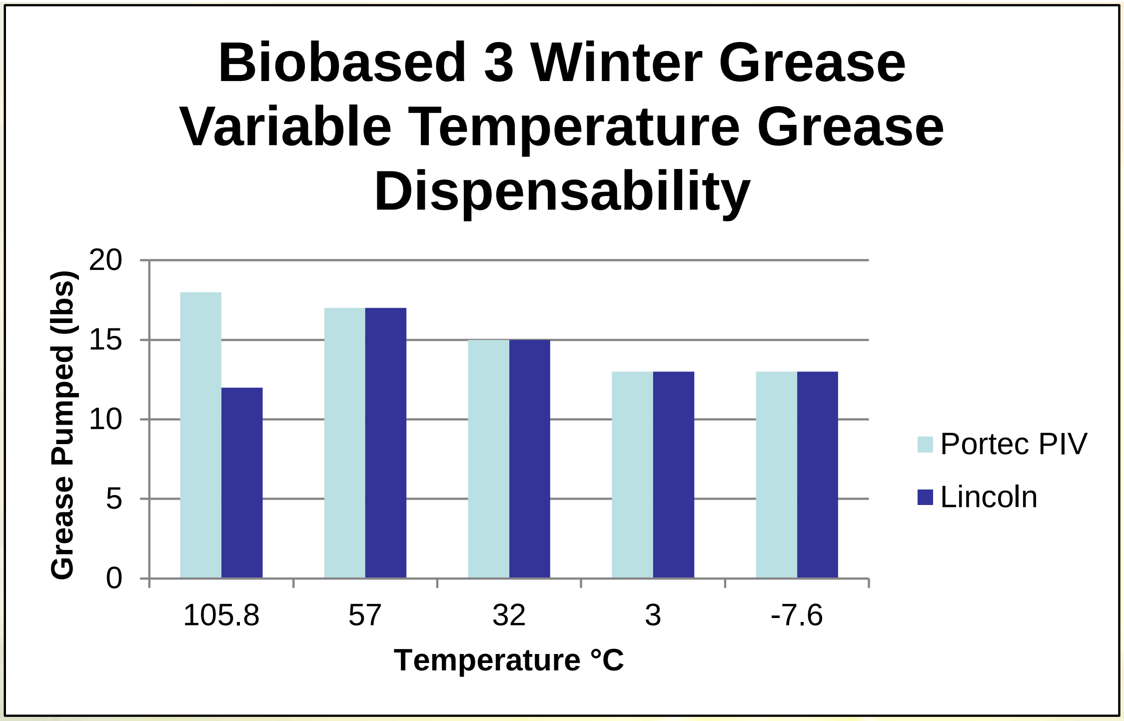


Figure 9: Amout of grease dispensed through each lubricator & penetrometer values at various test temperatures for Bio-Based Summer Grease 3



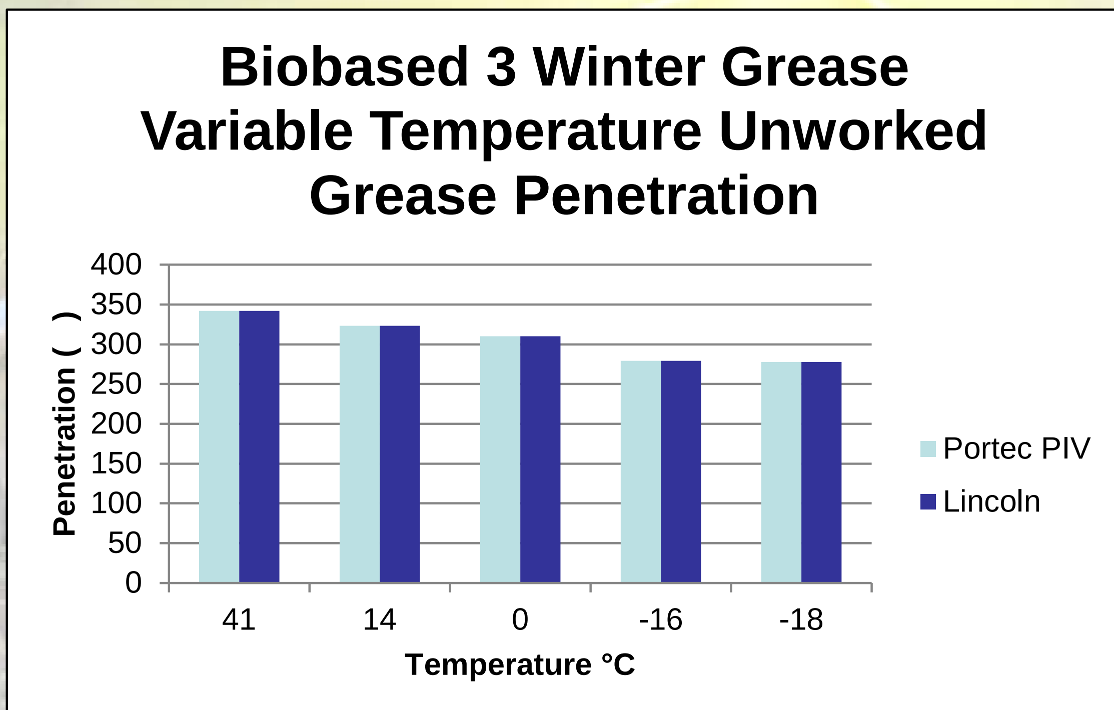


Figure 10: Amount of grease dispensed through each lubricator & penetrometer values at various test temperatures for Bio-Based Winter Grease 3

Figures 11 and 12 present the amount of grease dispensed and the penetrometer values at various test temperaures. In Figure 11, the winter version of one bio-based grease was pumped equally by both dispensers. However, the summer version in Figure 12 showed that one dispenser (Lincoln) pumped less than the second one (Portec) at colder temperatures.

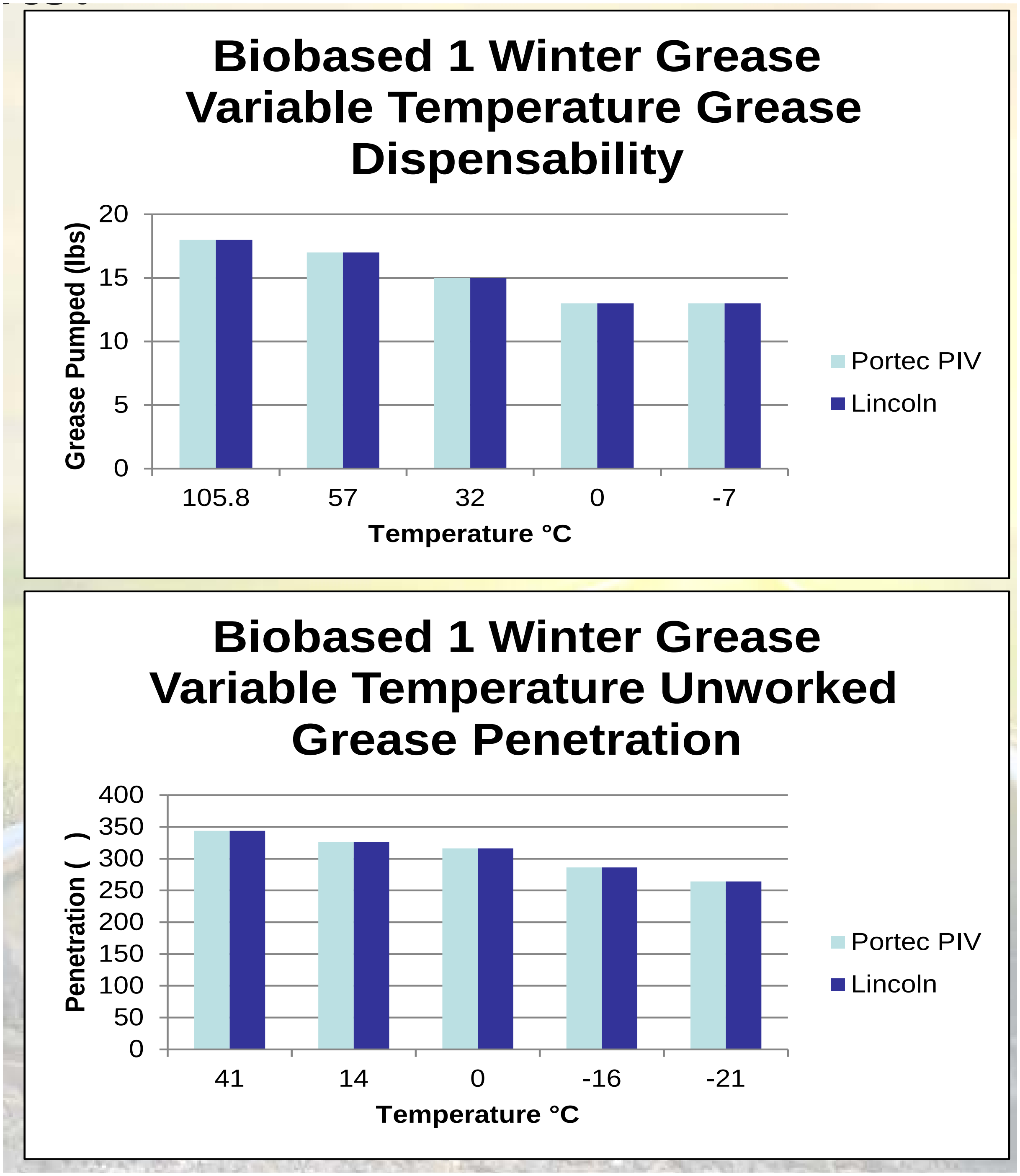


Figure 11: Amount of grease dispensed through each lubricator & penetrometer values at various test temperatures for Bio-Based Winter Grease 1

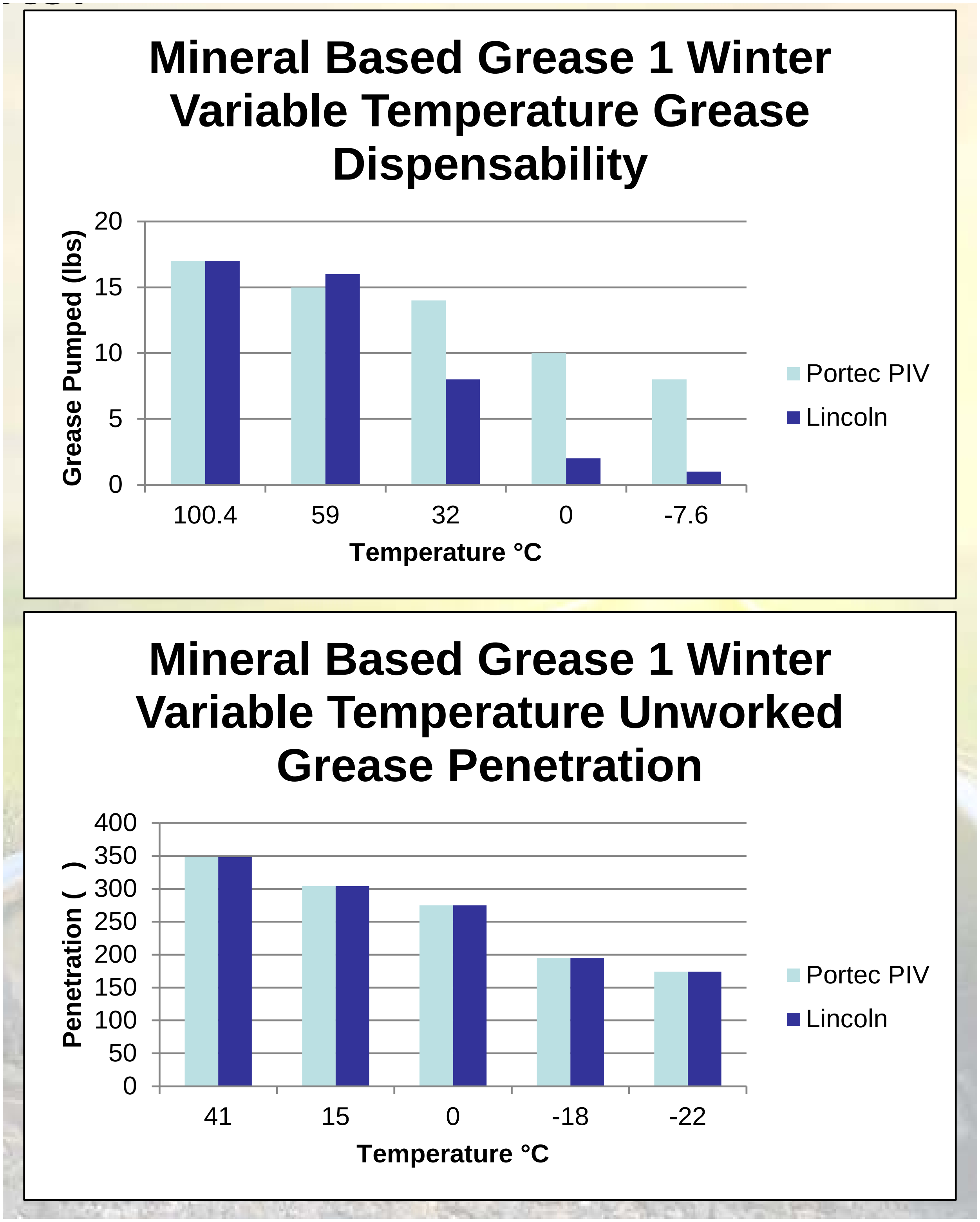


Figure 12: Amount of grease dispensed through each lubricator & penetrometer values at various test temperatures for Bio-Based Winter Grease 1

3.1.3 Conclusions

The environmental chamber tests provided an opportunity to test the performance of the dispensing equipment and the pump-ability of the test greases at different temperatures. In order to ensure that the bio-based greases were exposed to appropriately cold temperatures for the necessary periods of time, the grease and dispensing equipment were allowed a minimum of 24 hours exposure to the test temperatures before the tests. Additionally, the test greases were placed in standard cups that are used to test penetrations; the greases were then tested for penetration values at various test temperatures. The results could then be used to determine how mineral oil-based greases compare with bio-based greases at various temperatures. The results indicated that both grease types changed values as temperatures dropped and bio-based winter greases maintained their consistency as well as mineral oil-based greases.

The grease dispensing tests indicated that each lubricator has some advantages over the other at different temperatures. The operator's comment was that if some of the features of the two dispensers were combined, a more optimum dispensing system could be made available to users. The differences were largely related to the type of pump and valving used in each lubricator/dispenser. While one would pump better (as far as pumping the desired volume) at colder temperatures, the other provided more uniform output at higher temperatures. But, at the extreme temperatures both lubricators dispensed similar amounts of grease based on the test settings.

The general purpose of this test was to determine how bio-based greases and mineral oil-based greases pump through the hoses and dispensing bars and how the grease slumps in the reservoir. The performance of the OEM equipment was also observed during this process. Based on the results reported here, the test bio-based greases performed as well as, and in some cases better than, the mineral oil-based greases at the extreme colder temperatures. This finding is important because the cold temperature performance of bio-based (especially vegetable oil based) greases has been in question. The results of performance at extreme temperatures in the environmental chamber, when compared with the results obtained through laboratory testing—the grease mobility test and the Lincoln Ventmeter—should provide better insight into the performance of existing bio-based greases.

4. Field Testing

Field testing began in early February 2013 at two different sites in Cedar Rapids and Cedar Falls, IA. Two lubricators were housed at each site—one pumping petroleum grease to one track, and the other pumping bio-based grease to the other track. Each site had lubricators from different OEMs; the lubricators were therefore identified as OEM 1 and OEM 2. Tribometer readings for coefficient of friction were taken at 1 mile intervals up to 5 miles on each side of the lubricators. The results helped to show how the test grease would handle the extreme temperatures and how far each of the test greases would be carried down the track in a revenue service railroad.

Because of time limitations, only one bio-based winter grease was tested side by side with the reference mineral oil-based grease during the months of January, February, and March of 2013. Since May, the bio-based summer greases have been tested side by side with one reference petroleum grease.

Two lubricators from OEM 1 were already in use at the railroad. Two new lubricators from OEM 2 were acquired for the field test. The two existing lubricators were removed from the site and were refurbished to new condition by installing new components supplied by the manufacturer. Figure 13 shows the two existing lubricators with the components that were replaced.

Figure 13: Used components were removed (left) and new components provided by OEM 1 were installed on the cleaned out lubricators

Figures 14 and 15 show the lubricators at the Cedar Falls and Cedar Rapids test sites, respectively. One lubricator supplied grease to one side of the track, and the second one supplied it to the other side of the track. Both lubricators were placed next to each other to ensure the same environmental exposure. As shown in Figure 16, track mats were used to collect any spilled mineral oil-based grease.

After the installation of the lubricators on both sides, an attempt was made to adjust the delivery of each grease from each lubricator to approximately 0.4 lb per 100th wheel detected by the wheel sensor. This is the same amount of grease from each lubricator that was set to pump in the environmental chamber. The goal was to deliver approximately 0.8 lb grease per every 100 wheels that passed the wheel proximity sensor. The 0.8 lb/per 100 wheel is a rule of thumb recommended by members of the advisory committee of field engineers. The 0.8 lb/per 100 wheel number is used by the UNI-NABL Center to formulate the grease tackiness and consistency. A handheld tribometer was then used to measure the coefficient of friction at 1 mile intervals away from each lubricator (see Figure 17). Since each lubricator was dispensing grease to one side of the track, the tribometer readings were taken on both sides of the track at mile intervals from the lubricators.

Figure 14: The two refurbished lubricators were installed on the Cedar Falls test site; each lubricator had its bars on a different side of the track

Figure 15: The two new lubricators from the OEM were installed at the Cedar Rapids site

Figure 16: Track mats were used to collect any excess mineral oil-based grease at the lubricator site

Figure 17: Tribometer measurements taken at mile intervals on both sides of the track

4.1 Results

Based on the UNI-NABL interaction with the railroad industry, there seems to be a consensus that a coefficient of friction value between 0.25 and 0.30 is desirable for rail friction mitigation. Figures 18 and 19 present the coefficient of friction readings for the reference mineral oil-based grease and the only bio-based winter grease we were able to test. Each figure shows the test results from a different site. The mineral oil-based grease was the reference grease, and in the field test the reference grease was carried for nearly 5 miles down the track to the left of the lubricator. The bio-based grease had similar performance and showed a coefficient of friction value between 0.25 and 0.30. This was the only winter grease testing performed because of changes in weather. Although a reading of 0.65 coefficient of friction at the mile post 164 is an anomaly, both sides of the track showed the same result. Below mile post 163 was a rail yard which prevented further measurements. But, the results, as presented here, showed that both greases had carried to the mile post 172. The reference petroleum grease is currently the most commonly used grease by major railroads. The bio-based winter version of grease #3 shows performance similar in one direction and slightly better in the other direction from the lubricator location.

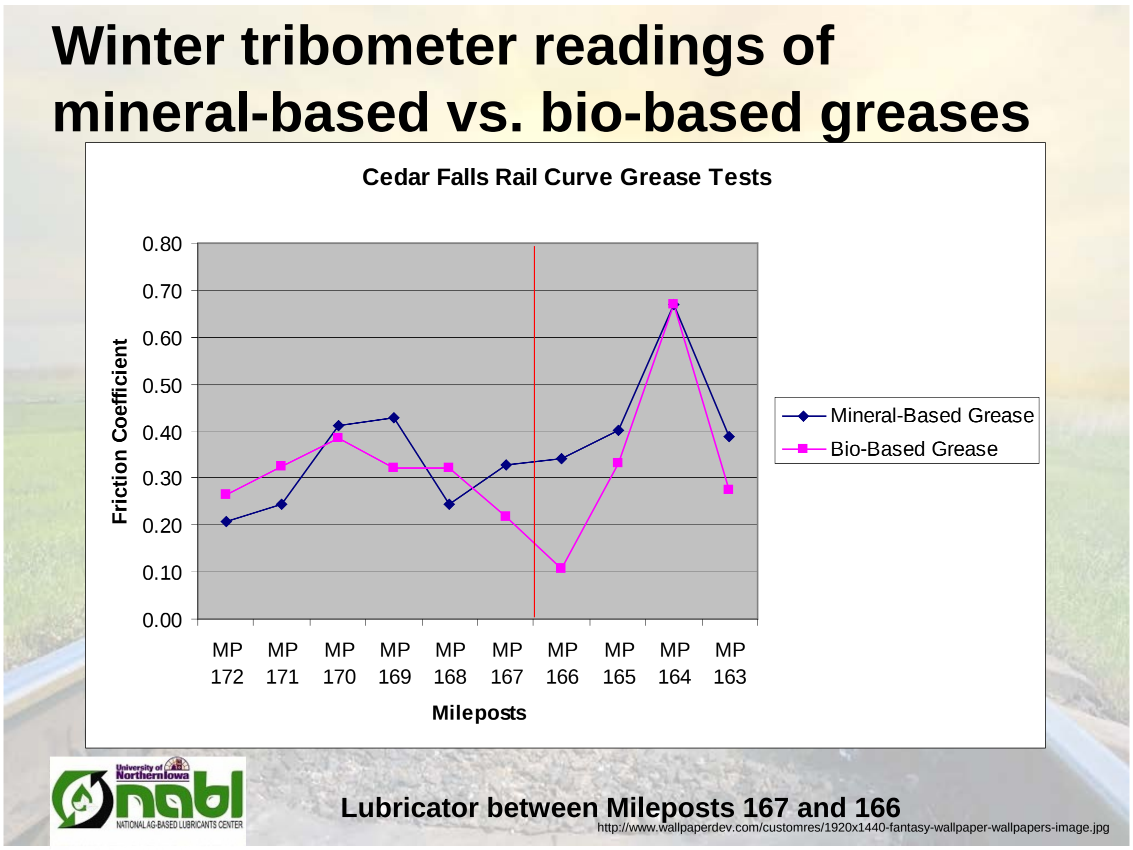


Figure 18: Tribometer measurements reported at mile intervals on both sides of the track for mineral oil-based grease on one track and bio-based grease on the second track (Cedar Falls location OEM1)

The Cedar Rapids location using the new lubricator from OEM 2 showed similar performance, as shown in Figure 19. On the right hand side of the track from mile marker 101, only two measurements could be taken because of the location of a rail yard 3 miles from the lubricator. However, on the left hand of the lubricator for 6 miles, both mineral oil-based and bio-based grease carried with coefficient of friction between 0.20 and 0.30.

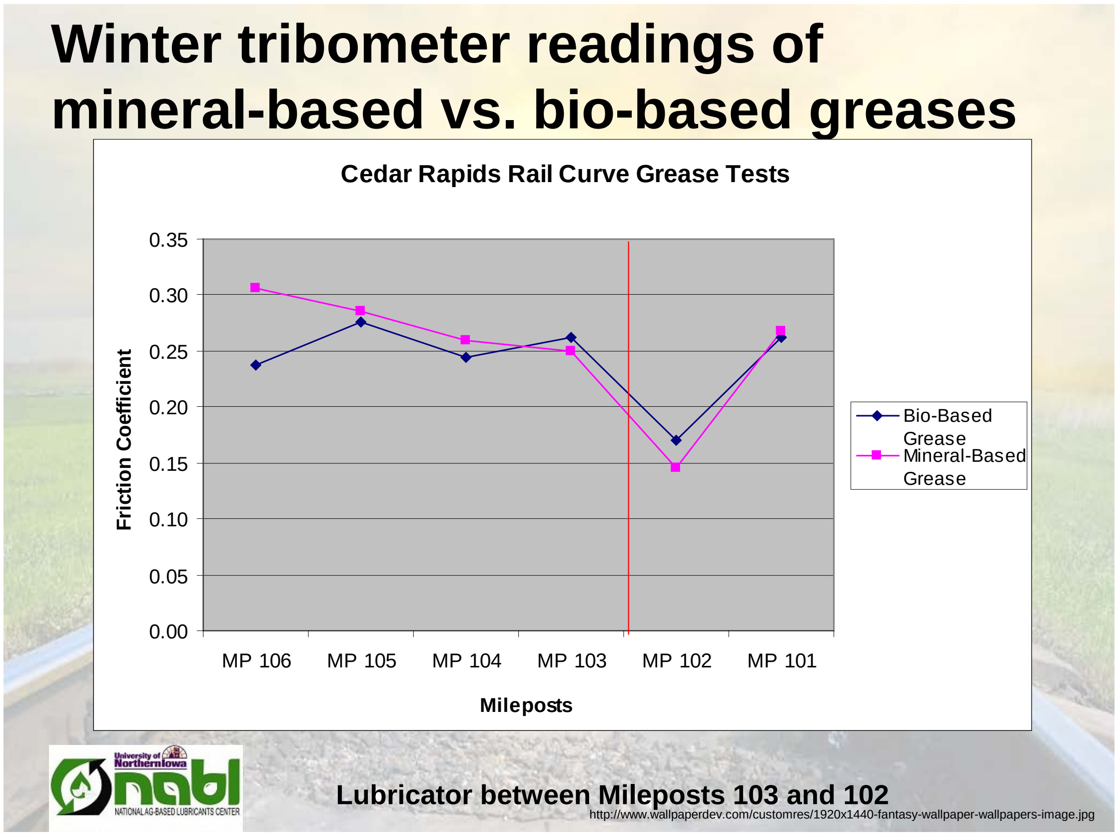


Figure 19: Tribometer measurements reported at mile intervals on both sides of the track for mineral oil-based grease on one track and bio-based grease on the second track (Cedar Rapids location OEM2)

Figures 20 and 21 present the coefficient of friction readings for the reference mineral oil-based grease and bio-based summer grease that were tested. Each figure shows the test results from a different site. The mineral oil-based grease was the reference grease and was shown to carry for nearly 5 miles to the left of the lubricator. The bio-based grease had similar performance and showed a value between 0.20 and 0.30. The operator reported that the mineral oil-based grease was not pumping as efficiently perhaps because of the transitional time of moving from winter to spring. But, the coefficient of friction readings for both greases were under 0.30. Again, for this summer grease test, the mineral oil-based grease was the reference grease and was carried down the track for nearly 4 miles to the left of the lubricator. The bio-based grease had similar performance and showed a value just above 0.30 at the 5 mile marker.

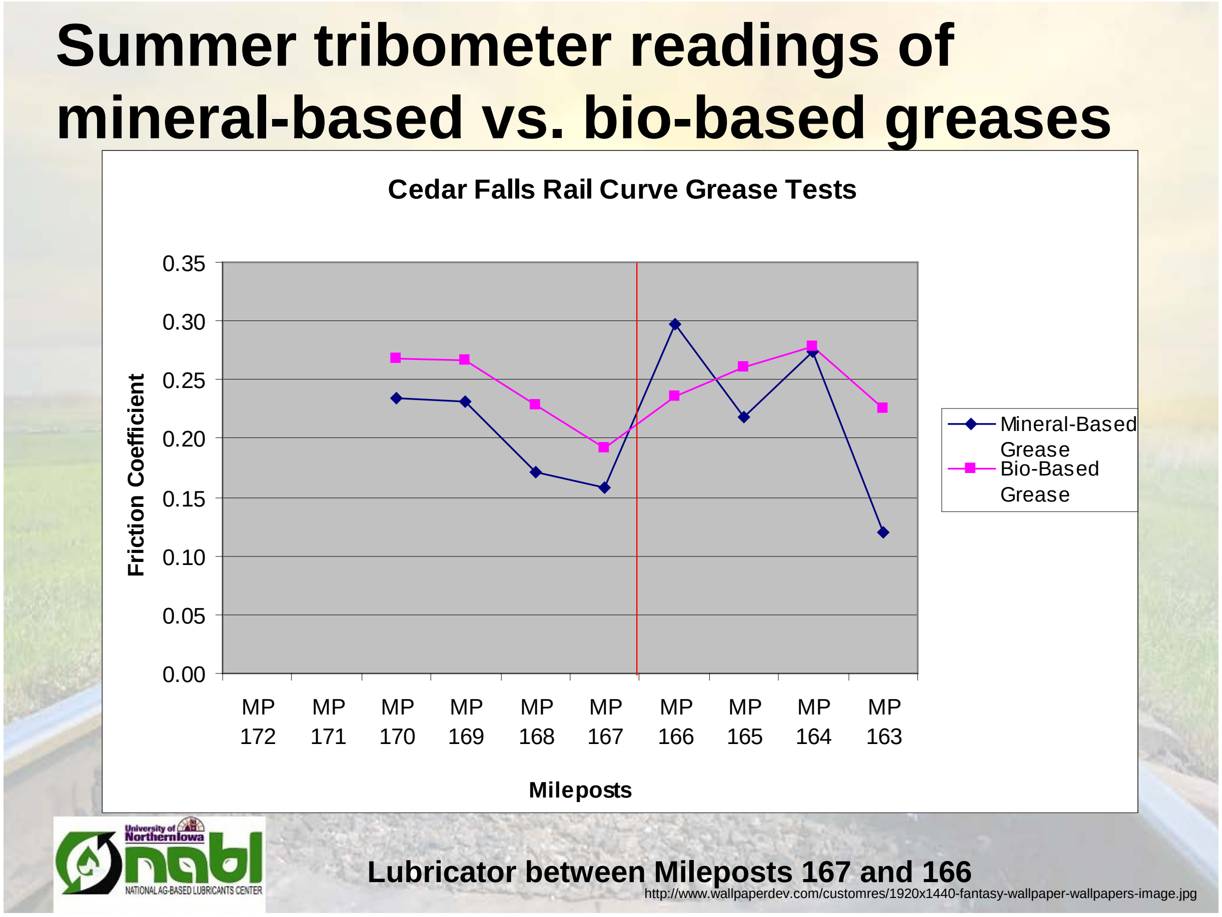


Figure 20: Tribometer measurements reported at mile intervals on both sides of the track for mineral oil-based grease on one track and bio-based grease on the second track (Cedar Fall location OEM1)

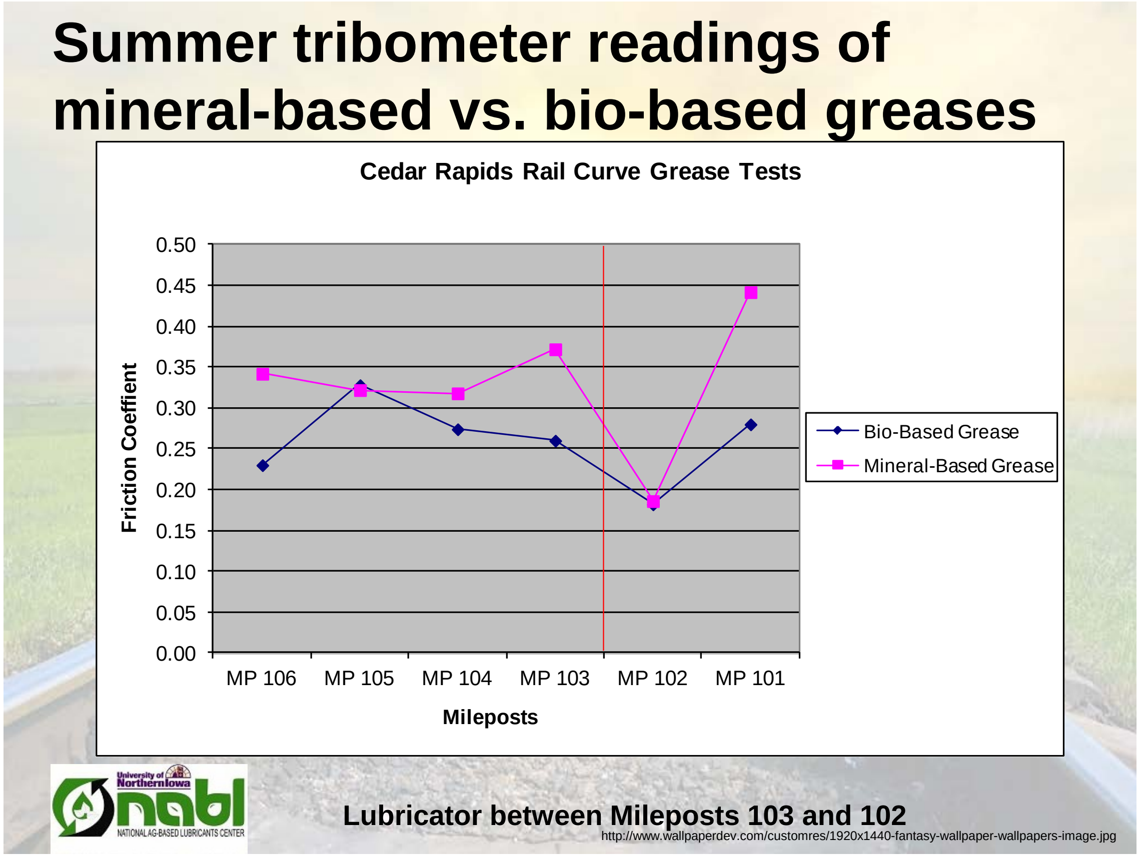


Figure 21: Tribometer measurements reported at mile intervals on both sides of the track for mineral oil-based grease on one track and bio-based grease on the second track (Cedar Rapids location OEM2)

Figures 22 and 23 present the coefficient of friction readings for the reference mineral oil-based grease and bio-based summer grease that were tested. Each figure shows the test results from a different site. The mineral oil-based grease was the reference grease and was shown to carry for nearly 5 miles to the left of the lubricator. The bio-based grease had similar performance and showed a value between 0.20 and 0.35. The operator reported that the mineral oil-based grease was not pumping as efficiently, perhaps because of the transitional time of moving from winter to spring. But, the coefficient of friction readings for both greases were under 0.30. Again, for this summer grease test, the mineral oil-based grease was the reference grease and was carried for nearly 4 miles on the left of the lubricator. The bio-based grease had similar performance and showed a value between 0.2 and 0.30.

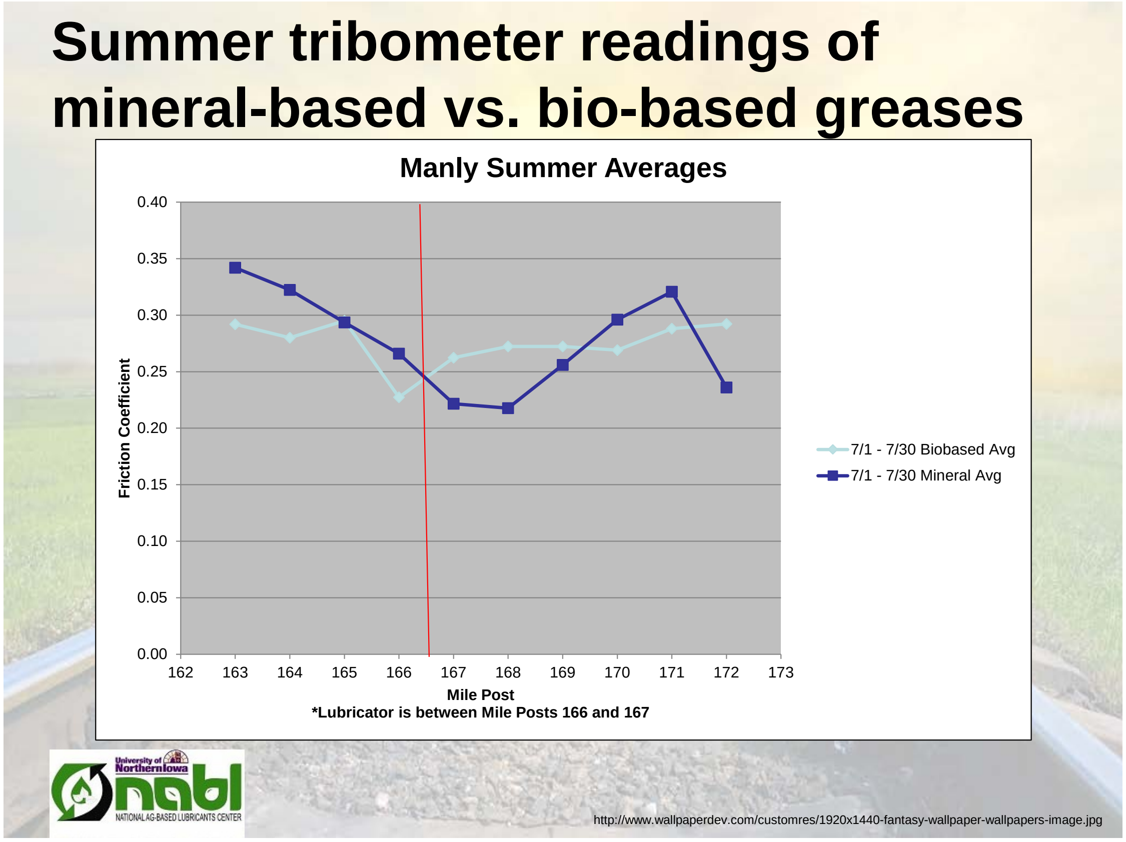


Figure 22: Tribometer measurements reported at mile intervals on both sides of the track for mineral oil-based grease on one track and bio-based grease on the second track (Cedar Rapids location OEM2)

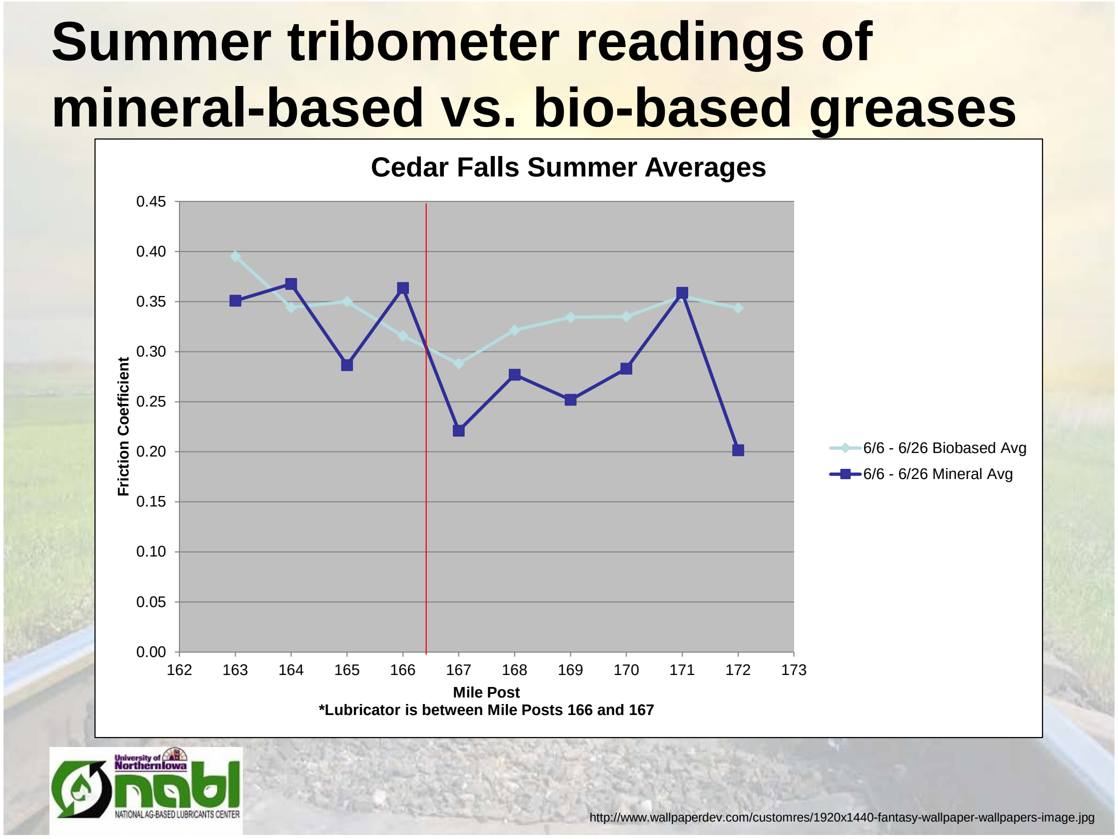


Figure 23: Tribometer measurements reported at mile intervals on both sides of the track for mineral oil-based grease on one track and bio-based grease on the second track (Cedar Falls location OEM1)

Figures 24 and 25 present the coefficient of friction readings for the reference mineral oil-based grease and bio-based summer grease that were tested. To the extent possible when the weather permitted, measurements were taken every 7 to 10 days. Operators avoided taking measurements during or shortly after heavy rains.

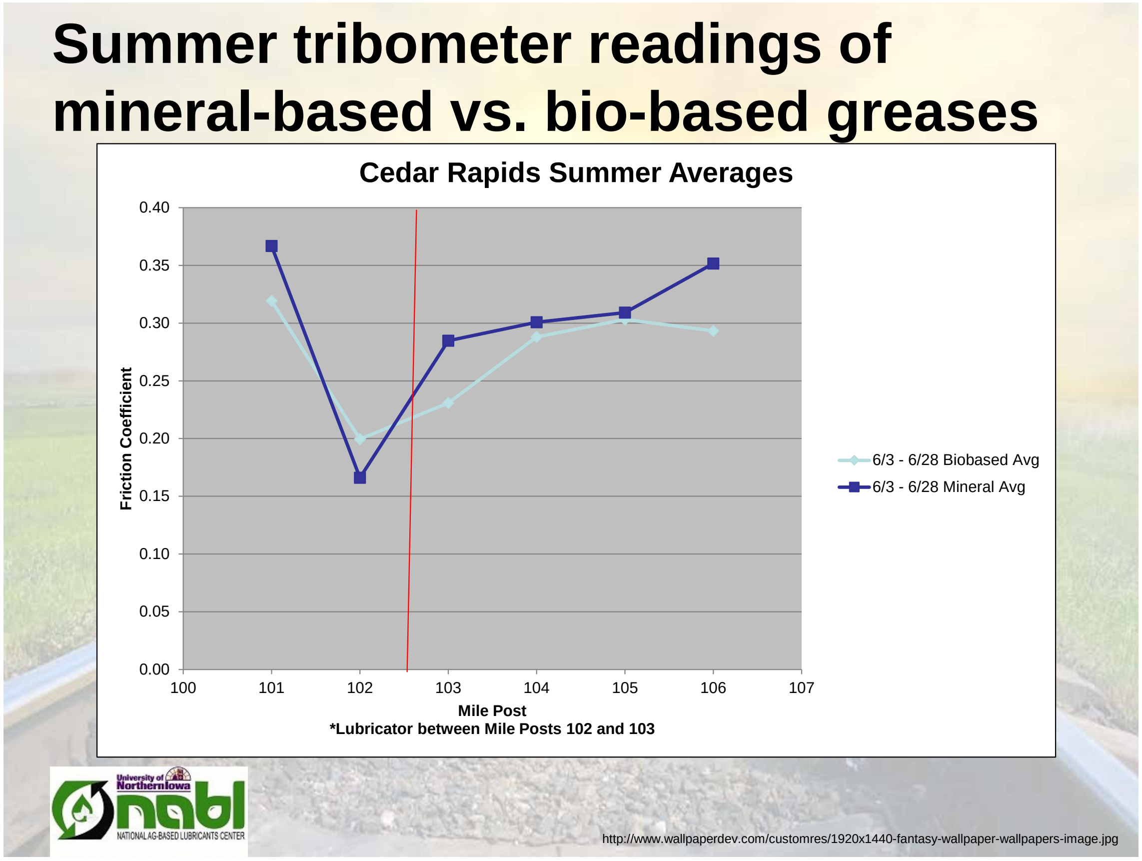


Figure 24: Tribometer measurements reported at mile intervals on both sides of the track for mineral oil-based grease on one track and bio-based grease on the second track (Cedar Rapids location OEM2)

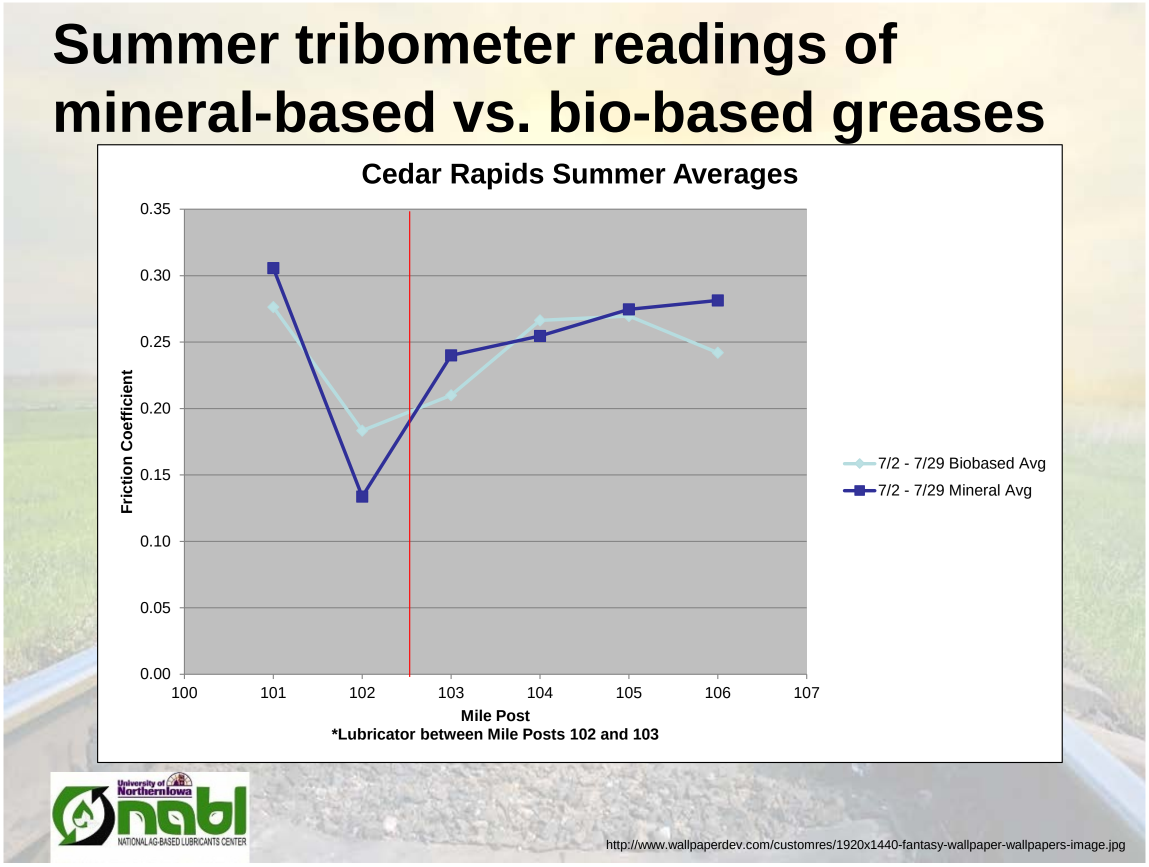


Figure 25: Tribometer measurements reported at mile intervals on both sides of the track for mineral oil-based grease on one track and bio-based grease on the second track (Cedar Rapids location OEM2)

Figure 26 presents the comparative test results for the same reference mineral oil-based grease and bio-based summer grease. During this week of testing, both mineral oil-based grease and bio-based grease performed outside the desired range of coefficient of friction of 0.30 with the grease dispenser from OEM1. Figure 27 presents the test results for the same mineral oil-based reference grease and the bio-based summer grease. During this week of testing, both mineral oil-based grease and bio-based grease performed near the desired range of coefficient of friction with the grease dispenser from OEM2.

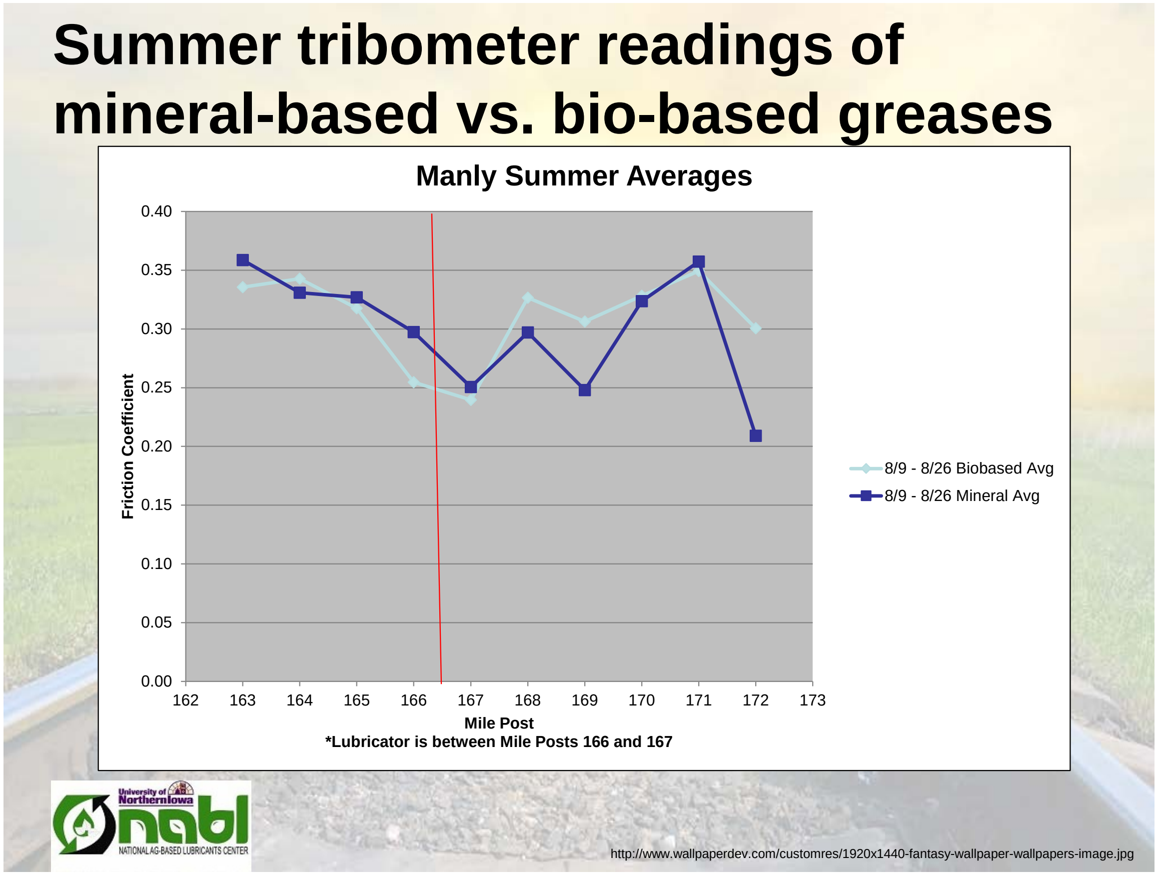


Figure 26: Tribometer measurements reported at mile intervals on both sides of the track for mineral oil-based grease on one track and bio-based grease on the second track (Cedar Falls location OEM1)

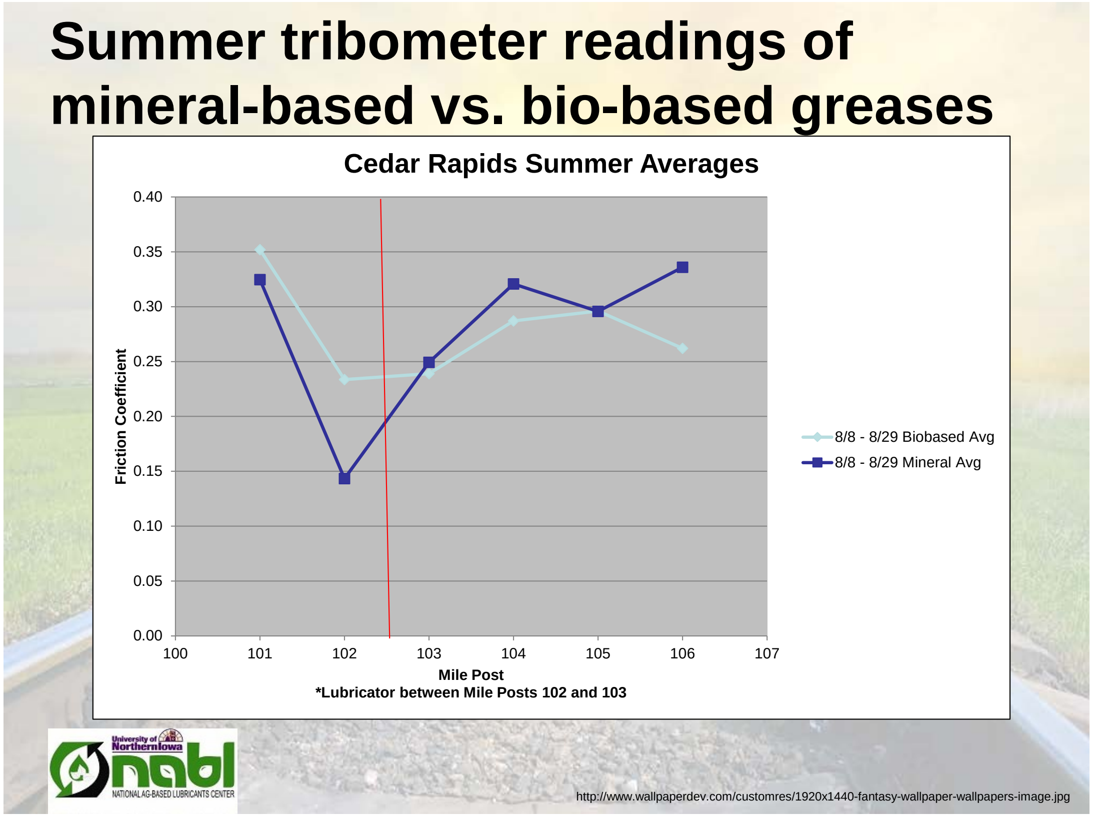


Figure 27: Tribometer measurements reported at mile intervals on both sides of the track for mineral oil-based grease on one track and bio-based grease on the second track (Cedar Rapids location OEM2)

4.2 Conclusions

The summer versions of three bio-based greases were tested next to one mineral oil-based reference grease. Each test took approximately 5 weeks with a 1 week time delay between each test to allow the residual grease from the old test to be consumed. Tribometer readings were taken every 7 to 10 days at 1 mile intervals both upstream and downstream from each lubricator site and on each side of the track. At each site, four sets of readings were taken: one at the downstream side for one track receiving the bio-based grease and one at the upstream side for the same track receiving the bio-based grease. Then the measurement was taken for the other track receiving the mineral oil-based grease both upstream and downstream from the location of the lubricator and on each side of the track. Since the mineral oil-based grease was the same for all four tests, at the beginning of each test the reservoir was topped off to the same level. Ten 5-gallon pails of grease were put in each reservoir at the beginning of each test and later used to level the grease. The results show that in general, bio-based greases performed as well as or better than the reference mineral oil-based grease. The three bio-based greases were from three different suppliers, two of which had indicated that the bio-based grease was vegetable oil based. The nature of the base oil for the third bio-based grease is not known, but the manufacturer markets the product as bio-based. The results coincide with the performance of the greases observed in the environmental chamber. The operators reported that the mineral oil-based grease is excessively tacky with tackiness that approaches the consistency of glue. Based on observation, the grease shows a high level of cohesiveness which could be helpful for pumping at colder temperatures. But, excessive cohesion comes at the cost of diminished adhesion which could reduce the distance the grease is carried down the track.

There are many performance variables that cannot be controlled in the field or by the equipment. The main conclusion that can be drawn from the data is that bio-based greases can pump and carry in the tested lubricators. Their extreme pressure property was superior to that of the petroleum greases as observed in the laboratory test results. The following section covers the environmental aspects of the test greases.

5. Test of Adhesion and Cohesion – Grease Tackiness

An important property for rail curve grease is its ability to adhere to metal surfaces such as the wheel flange and the track (gage face). However, for the grease to pump at extreme cold temperatures, it needs to have a certain degree of cohesiveness that allows it to adhere to itself like taffy when pulled apart. When the grease is drawn into the inlet of the pump in a grease reservoir, too much adhesion could result in the grease sticking to the wall of the reservoir, creating a funneling effect which could result in pump cavitation. Proper cohesion would result in the grease being pulled into the inlet of the pump and away from the walls of the reservoir. Too much cohesion, on the other hand, could cause the grease to sling off the wheel flange at high speed and build up under the cars. A proper level of adhesion and cohesion is necessary for grease to perform well during the pumping and after it is applied to the wheel flange and subsequently to the gage face. The grease tackiness is complex and grease formulators resort to using multiple additives to achieve the desired effect. Polymer and elastomeric additives are used to create the proper tackiness for the grease, but there are still no guarantees that the grease will maintain the achieved tackiness when exposed to extreme temperatures because polymers and elastomers behave differently at those temperatures.

Conventionally, makers of the rail curve grease try to determine the tackiness of the grease by squeezing the grease between thumb and index fingers and then pulling away to observe stringiness (cohesion) and strings clipping or breaking (adhesion). Sometimes, operators video record the grease when it is being applied to the wheel flange and then analyze the stringiness of the grease to determine if the right degrees of adhesion and cohesion are present.

Researchers at the UNI-NABL Center have experimented with a method of using a flat disk that is balanced to run at high speeds in a modified centrifuge. This test allows the operator to place a set quantity of grease at a predetermined distance from the center of the disk and then rotate the disk to a set revolution per minute (rpm) for a given period of time. At high speeds and over time, the grease on the disk spreads to create different patterns; some of it also slings off the disk and onto the sides of the centrifuge. The sprayed off grease can be collected and weighed to determine how much grease stayed on the disk. The benefit of this method is that a new grease can be matched to the patterns of a reference grease.

5.1 Test Method Description

Figure 28 shows the 18 inch diameter balanced aluminum wheel used for this test. 2.5 grams of each grease was placed on the disk at distances of 2.5 inches, 4 inches, and 8 inches away from the center of the centrifuge. A specially designed ring was used to ensure uniform grease placement on the disk. The centrifuge was operated at three different speeds (500, 750, and 1000 rpm) for tests periods of 10 seconds and 20 seconds. As a result, each sample grease went through 18 tests at different distances from the center, for different time periods, and at different speeds. This section of the report presents the grease patterns, as pictured after each run, as well as the corresponding graphs showing the side by side results of the grease with each variable. Table 6 shows a sample table for reporting the centrifuge test results of each grease tested. Table 14 shows the format used to record the amount of grease after each run.

Figure 28: An aluminum disk with 18" diameter inside a centrifuge for testing grease tackiness

Table 14: Sample table to report the centrifuge test results for each grease

Grease Quantity (grams)	Distance from Center of Disk 2.5"	Grease Quantity after Test (grams)	Distance from Center of Disk 2.5"	Grease Quantity after Test (grams)	Distance from Center of Disk (inches) 2.5"	Grease Quantity after Test (grams)
2.5 +/- .3	500 rpm – 10 sec		750 rpm – 10 sec		1000 rpm – 10 sec	
2.5 +/- .3	500 rpm – 10 sec		750 rpm – 10 sec		1000 rpm – 10 sec	
2.5 +/- .3	500 rpm – 10 sec		750rpm – 10 sec		1000 rpm – 10 sec	

5.2 Results

The following figures highlight the results of some of the individual grease testing. A review of the results at different speeds and distances from the center clearly shows the effect of centrifugal force at different distances, rpm, and time. The balance of the test data in the form of charts and figures appears in Appendix A.

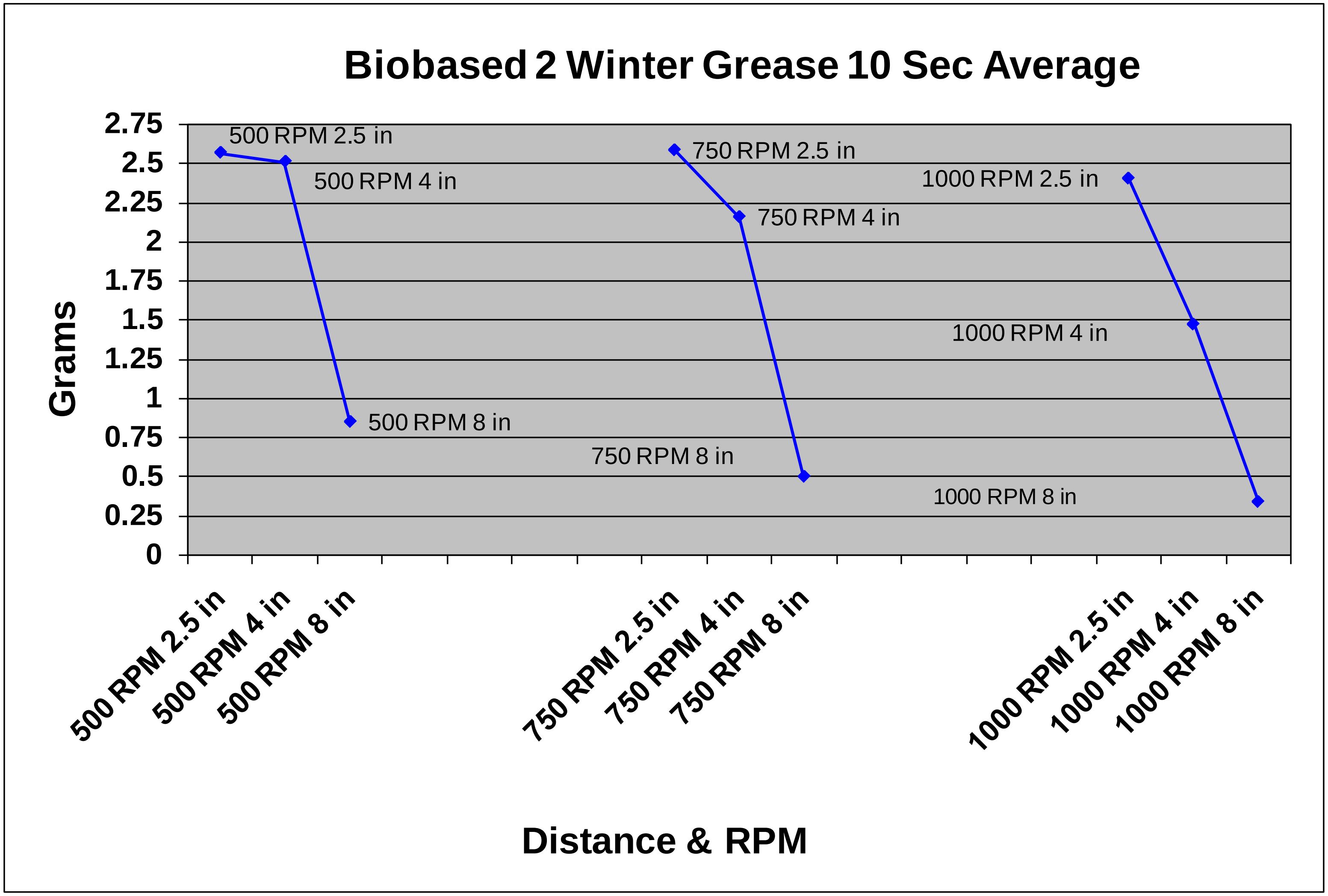


Figure 29: Centrifuge test results for the winter bio-based grease 2 at different distances from the center and different RPMs in 10 second runs

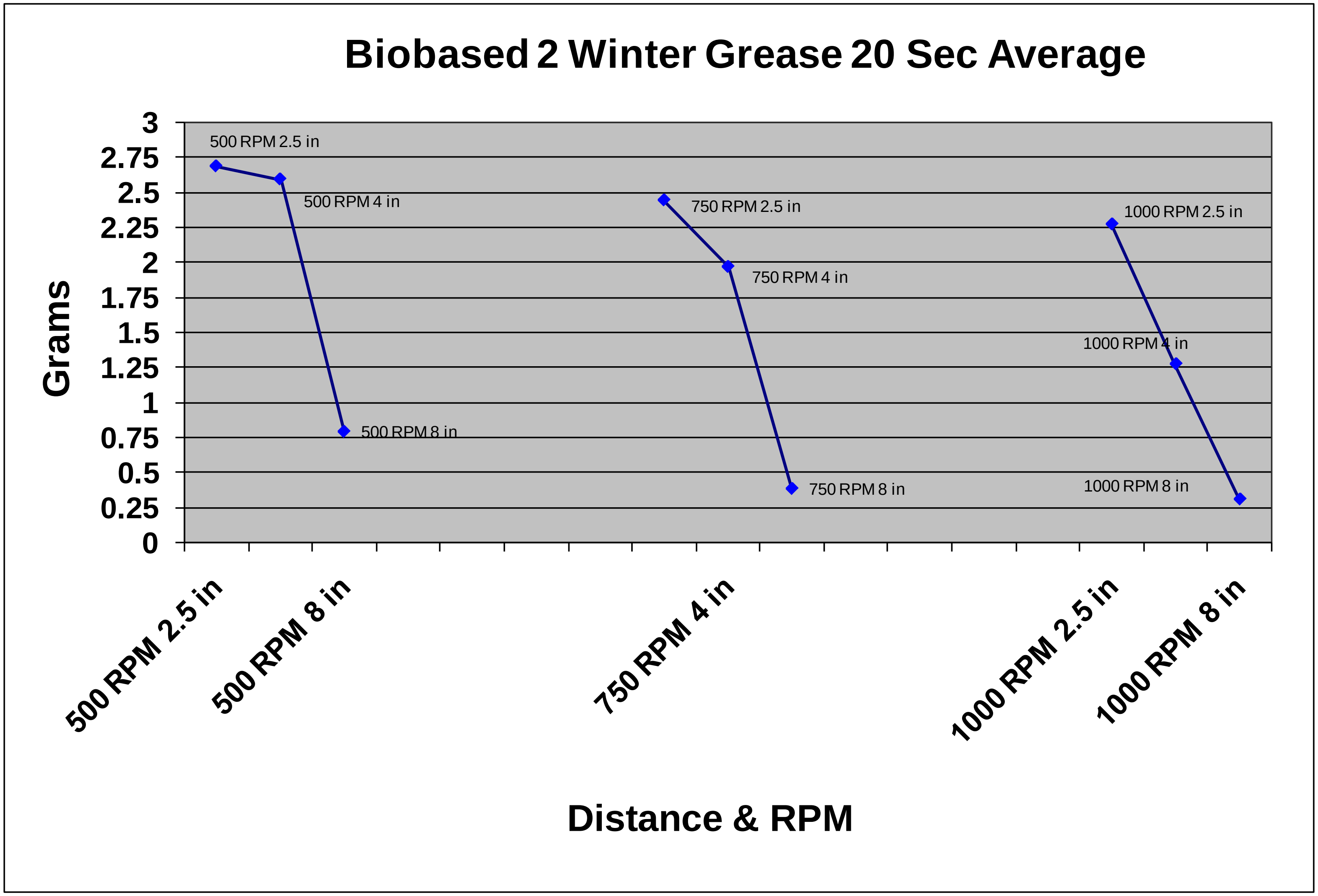


Figure 30: Centrifuge test results for the winter bio-based grease 2 at different distances from the center and different RPMs in 20 second runs

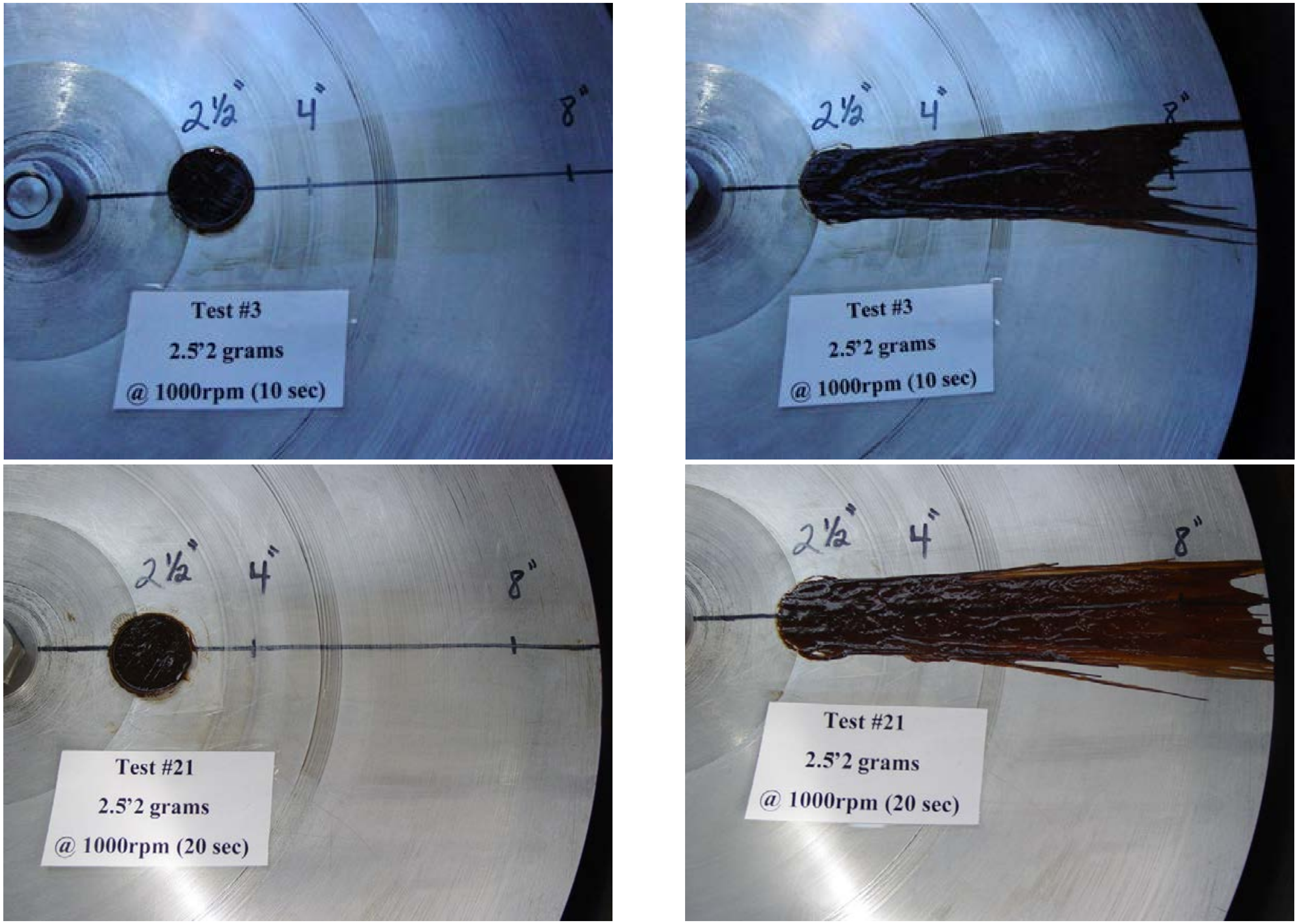


Figure 31: Patterns of the winter bio-based grease #2 for 10 seconds and 20 seconds at 2½" distance from the disk center

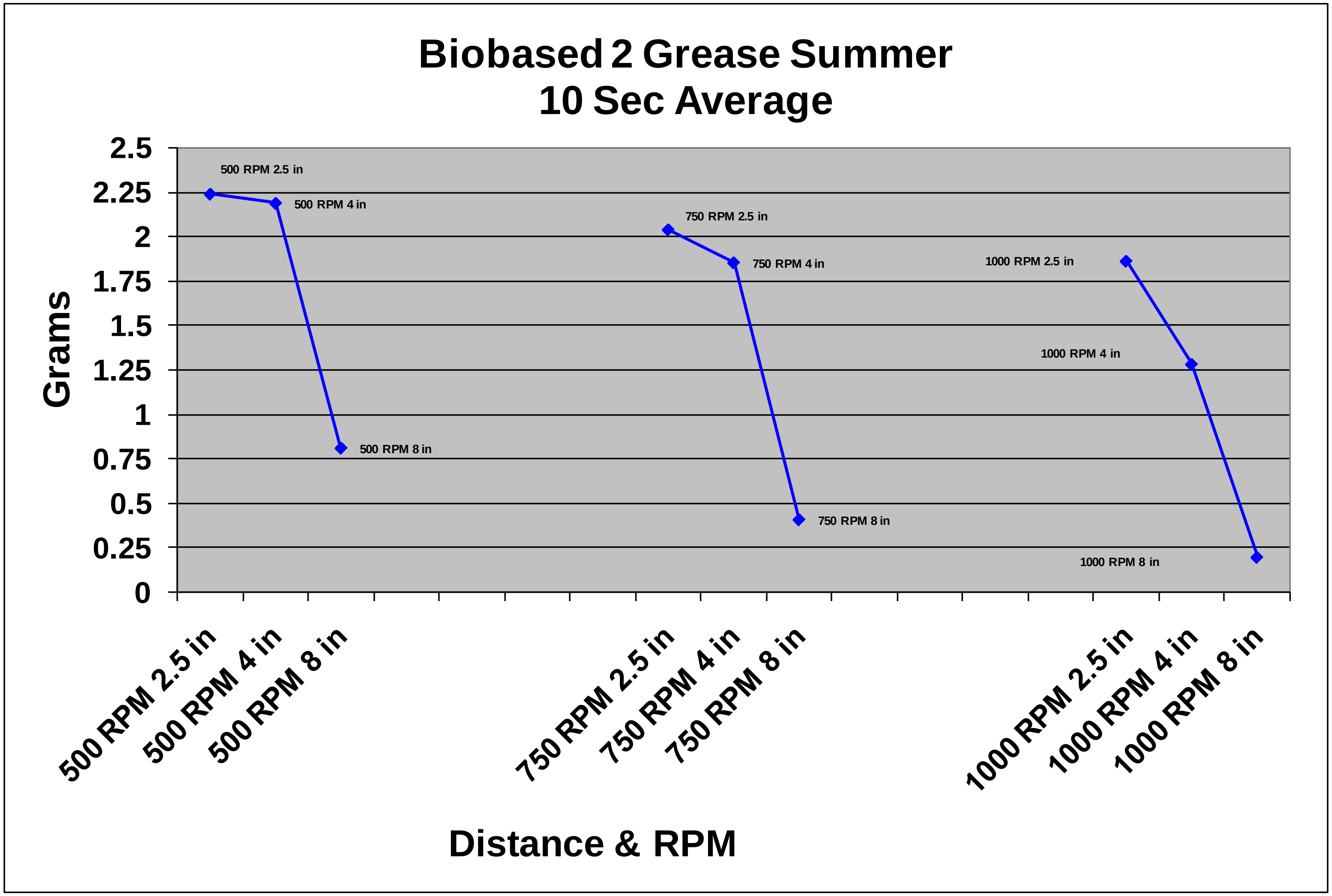


Figure 32: Centrifuge test results for the summer bio-based grease 2 at different distances from the center and different RPMs in 10 second runs

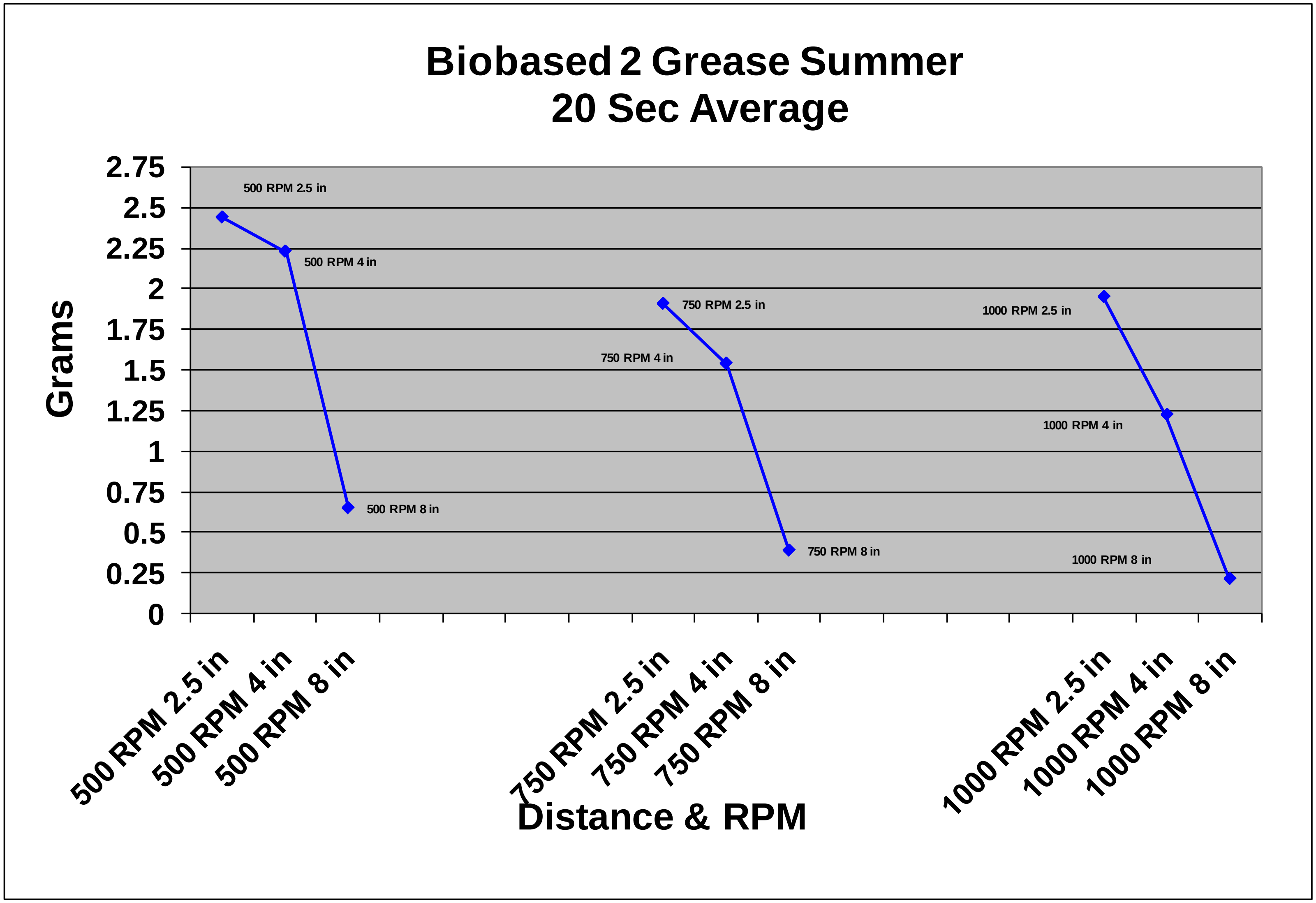


Figure 33: Centrifuge test results for the summer bio-based grease #2 at different distances from the center and different RPMs in 20 second runs

Figure 34: Patterns of the summer bio-based grease #2 for 10 seconds and 20 seconds at 2½" distance from the disk center

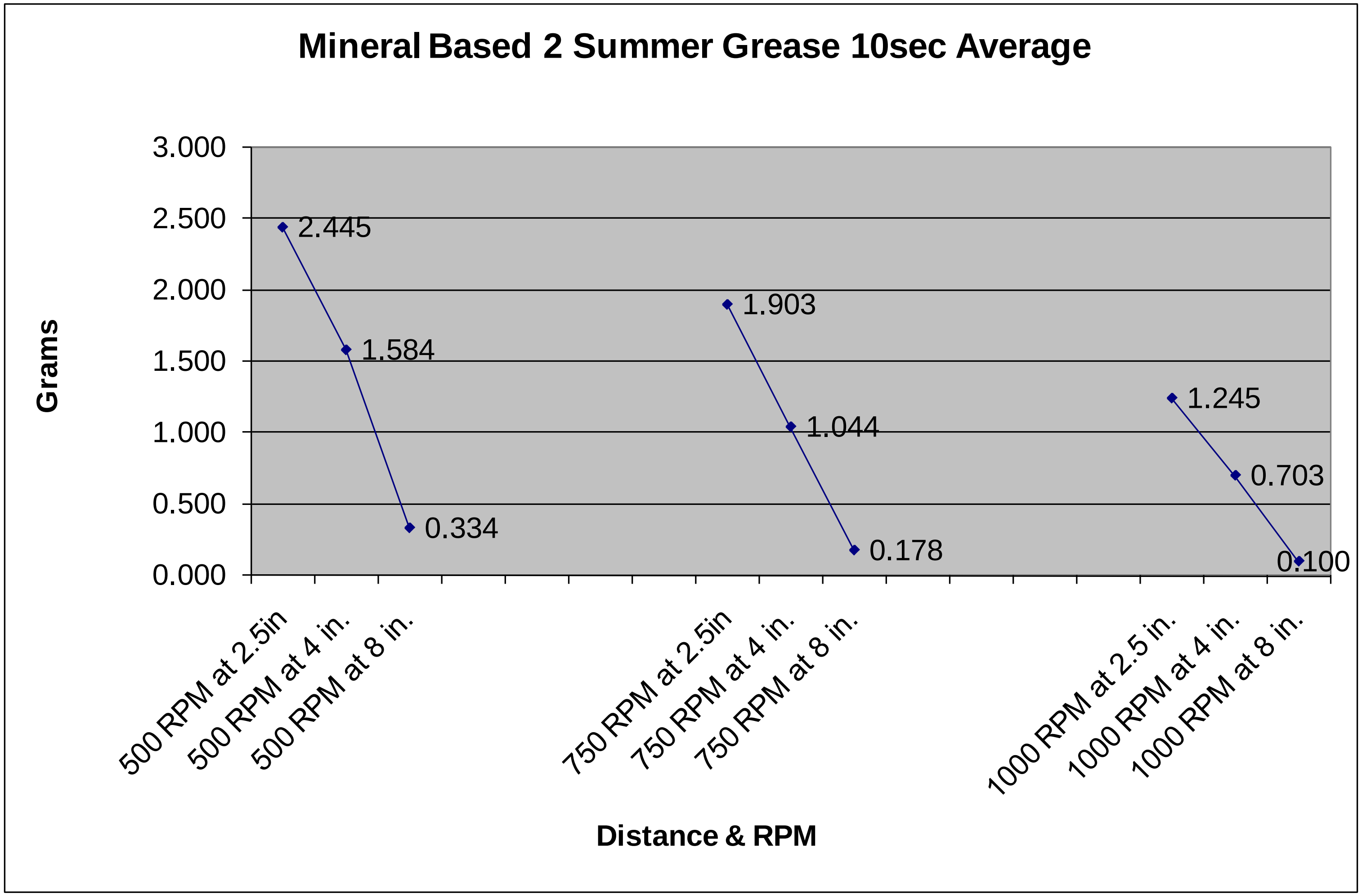


Figure 35: Centrifuge test results for the summer mineral oil-based grease #2 at different distances from the center and different RPMs in 10 second runs

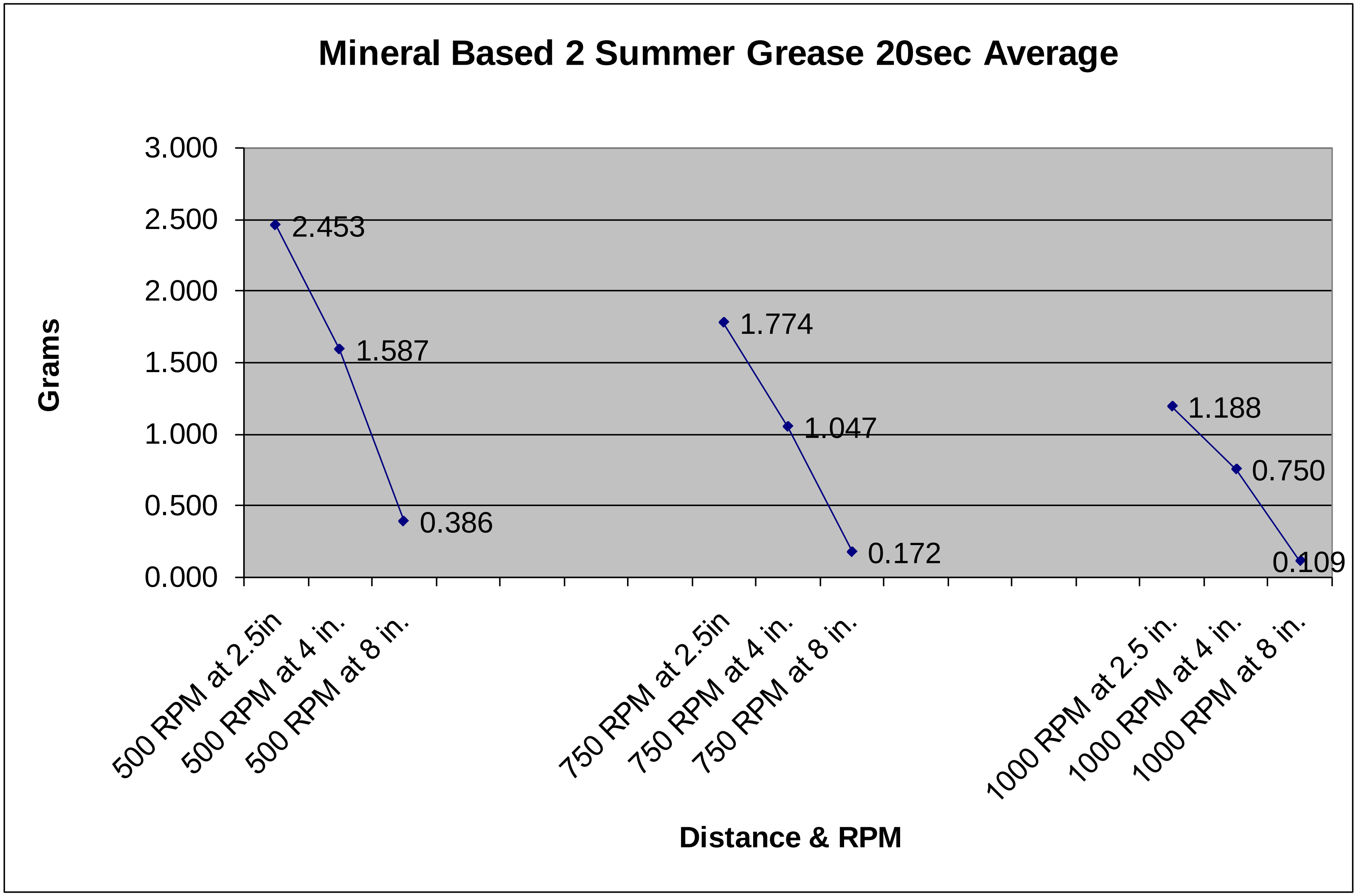


Figure 36: Centrifuge test results for the summer mineral oil-based grease #2 at different distances from the center and different RPMs in 20 second runs

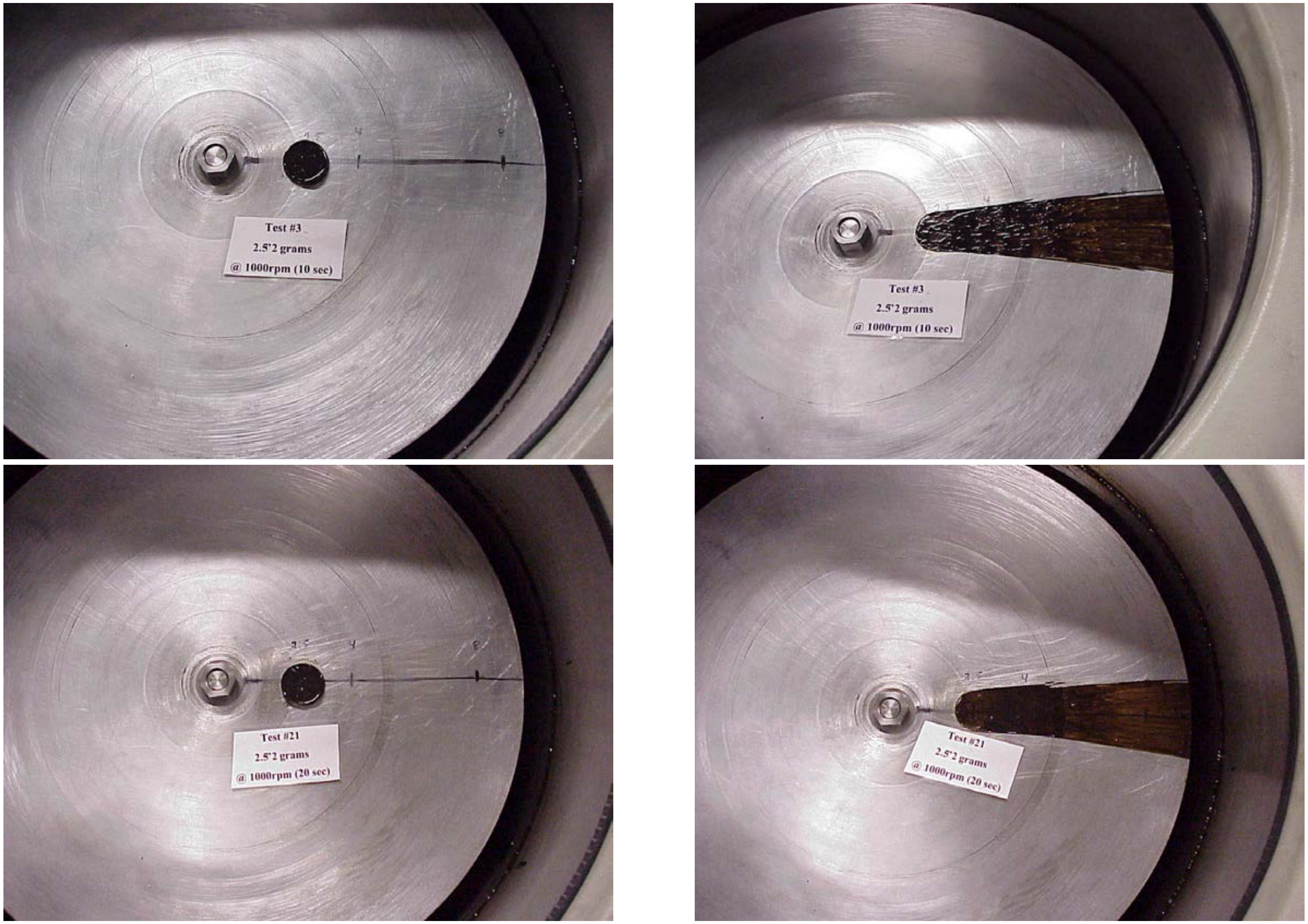


Figure 37: Patterns of the summer mineral oil-based grease #2 for 10 seconds and 20 seconds at 2½" distance from the disk center

5.3 Conclusions

Since adhesion and cohesion are important properties for rail curve greases, researchers at UNI_NABL developed a test method to establish patterns and processes for future use. A review of the results at different speeds and distances from the center clearly shows the effect of centrifugal force at different distances, rpm, and time. From the data, it appears that the speeds of 750 and 1000 rpm may be excessive as the majority of the grease is thrown off the disk.

Future research to determine the optimum quantity, distance from the center, and time period for testing is needed to better assess the validity of this test method in determining the cohesion and adhesion properties of rail curve greases. At minimum, the method appears to be useful for comparison of a new grease with an exising grease. To further refine this method, the disk could be made to run vertically, with the centrifuge in an environment chamber, and at different temperatures.

The results also showed that the tested bio-based greases have sophisticated formulations and their adhesion and cohesion properties match those of the mineral oil-based greases with years of market experience.

6. Bio-Based Content

The USDA bio-based labeling requirements include determining the percentage of renewable carbons as an indicator of the bio-based content. The test method used was the ASTM D6866, “Standard Test Methods for Determining the Bio-Based Content of Solid, Liquid, and Gaseous Samples Using Radiocarbon Analysis.” Table 15 shows the percentage of bio-based content for the test greases in this study.

Table 15: Percentage of renewable carbon (bio-based content) in test greases

Grease Name	% Renewable Carbon (bio-based content)
Bio-Based 1 Summer	61 %
Bio-Based 1 Winter	65 %
Bio-Based 2 Summer	81 %
Bio-Based 2 Winter	61 %
Mineral Oil-Based 3	8 %
Mineral Oil-Based 1 Cold Temp	10 %
Mineral Oil-Based 1 Summer	7 %
Mineral Oil-Based 1 Winter	6 %
Mineral Oil-Based 2 Summer	5 %
Mineral Oil-Based 1 Winter	5 %
Bio-Based 3 Summer	39 %
Bio-Based 3 Winter	42 %

Two of the bio-based greases (#1 and #2) in Table 15 above had bio-based content levels of 61 to 81 percent, a range which is above the USDA minimum requirement for bio-based rail curve greases (43 percent). The third bio-based grease, #3, had less than the minimum content required to meet the labeling regulations of the USDA Biopreferred program. All of the mineral oil-based greases showed low bio-based content.

Conclusions

The bio-based content of greases is an indication of the percentage of renewable hydrocarbon typically derived from plant or animal sources. The USDA Biopreferred program has established a list of minimum bio-based content requirements for a product to be classified as bio-based. Of the three sets of summer and winter bio-based greases that were tested, one set did not meet the minimum USDA requirements for bio-based content, while two sets of summer and winter greases met and even exceeded those minimum requirements. As expected, the mineral oil-based greases showed minimal bio-based content which can be explained by the presence of the stearic acid often used to formulate the lithium or lithium complex greases. In sourcing bio-based greases, it is important to ensure that the product contains the required minimum amount specified by the USDA.

7. Biodegradability

To test the biodegradability of grease products, a quantity of grease is dissolved in a sample, which along with some reference samples, is placed in a controlled environment and then inoculated with standard specified bacteria. The test runs for 28 days and as bacteria consume food or the biodegradable materials, they consume the oxygen and release carbon dioxide. After consuming all the nutrients in the sample, the bacteria begin to die out and oxygen consumption flattens out and then drops. The Organization for Economic Cooperation and Development (OECD) 301 series tests corresponding to the United States Department of Agriculture (USDA) tests monitor either oxygen consumption or carbon dioxide evolution. Testing grease in the current biodegradability instruments is difficult because grease does not easily dissolve in water. Because of time limitations, the research team selected the reference petroleum grease which was used in all the field tests, as well as one bio-based grease that had shown high bio-based content, for comparative testing.

7.1 Test Method

The test method used was the OECD 301 test which is a 28-day test. The bio-based grease proved to be biodegradable according to the test method; the mineral oil-based grease, on the other hand, did not meet the percent oxygen consumption required by the test and thus was not considered biodegradable.

Normally, this test is run using oil samples; but since it required the use of grease samples, it had to be modified to accommodate the change. The sole change made to the test was how the sample was introduced to the water. Normally 100 milligrams (mg) of the sample is put directly into the water. For grease, the team spread the required 100 mg weight of grease onto half a piece of filter paper and placed it into the water. This strategy helped in two different ways: First, it helped keep the grease from accumulating on the side of the bottle and not being fully exposed to the bacteria. Second, it helped the researchers to get an accurate weight of the sample; the filter paper made it possible to spread the sample on the paper and then weigh it. All other aspects of the test remained the same, and the test was run for 28 day at 22 degrees Celsius.

One error occurred during the test: the first De-Ionized (DI) water trial for the mineral oil-based grease had a result that was unusual. The normal result for the DI water is in the 2–12 mg range, but the reading obtained at the end was approximately 100,000 mg. The results are shown in the graphs by the amount of oxygen consumed by the bacteria.

7.2 Results

Samples containing sodium benzoate, which is the reference food for the bacteria, show a rapid growth in the oxygen update. The test requires that within the first 10 days of the test, the oxygen update by the test sample reaches 60 percent of the reference sample. The test is continued for 28 days and the oxygen update continues at these levels if the product can be consumed to sustain the test bacteria. Figure 38 shows the raw charts from the test report indicating that sample of mineral oil-based greases did not result in oxygen updates approaching 60 percent of the reference samples; so the tested mineral oil-based greases cannot, in effect, be considered biodegradable.

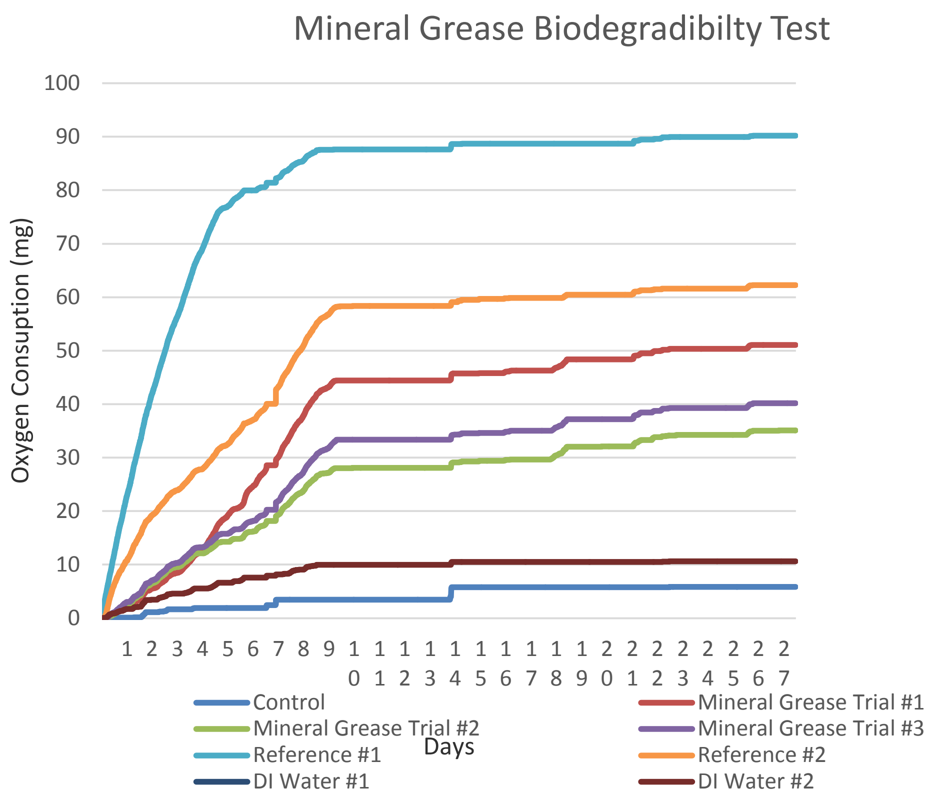


Figure 38: Results from biodegradility test of the reference mineral Oil-Based Grease

The testing of the bio-based grease, on the other hand, showed oxygen uptakes in line with the reference samples at the 10th day mark and throughout the 28 day test. The product could therefore be classified as biodegradable.

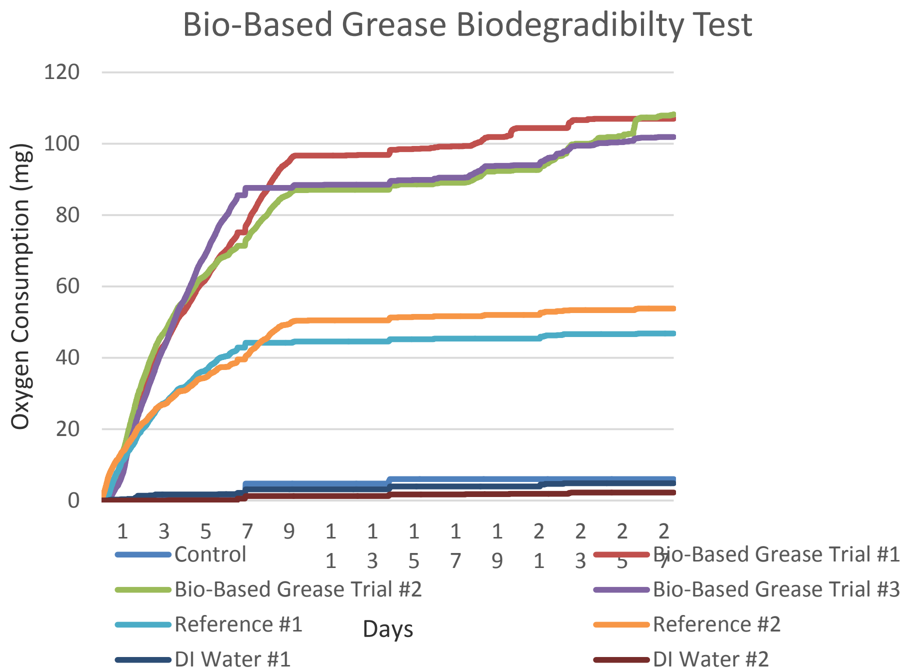


Figure 39: Results from biodegradability of bio-based grease test

7.3 Conclusions

Bio-based greases tested here were shown to contain a significant amount of bio-based content and to be biodegradable. Since these greases have been shown to perform in the field and in the environmental chamber, use of bio-based greases such as those tested could potentially reduce concern about environmental impact.

8. Aquatic Toxicity

The test for aquatic toxicity was conducted using the OECD 202, Daphnia Sp. Acute Mobilization Test and Reproduction Test. The significance of this test is that it uses *daphnia magna* as the test specimen. *Daphnia magna* refers to sensitive invertebrate that are impacted by the presence of slightly toxic materials. This test method is simpler than comparable methods that require rainbow trout and other fish species. Bio-based greases are often also biodegradable. But, it is important to determine their impact on the aquatic organisms in case of spills or exposure to water.

8.1 Test Method

The OECD 202 test is an acute toxicity test to assess the effects of chemicals on *daphnia magna*. The test requires young daphnids, less than 24 hours old at the start of the test, to be exposed to the test substance at a range of concentrations (at least five concentrations) for a period of 48 hours. Immobilization is recorded at 24 hours and 48 hours and compared with control values. The results are analyzed in order to calculate the half maximal Effective Concentration (**EC_{50}**) at 48 hours. Determination of the EC_{50} at 24 hours is optional. At least 20 animals, preferably divided into four groups of five animals each, should be used at each test concentration and for the controls. At least 2 millimeter (ml) of test solution should be provided for each animal (i.e., a volume of 10 ml for five daphnids per test vessel). The limit test corresponds to one dose level of 100 mg/L. The study report should include the observation of the immobilized daphnids at 24 and 48 hours after the beginning of the test, as well as the measures of dissolved oxygen, pH, and concentration of the test substance at the beginning and end of the test. The following table shows classification of toxicity based on the effective loading.

Table 16: Classification of toxicity based on effective concentration

Classification	EL_{50}* mg/L
Highly Toxic	≤ 1
Toxic	> 1 to 10
Slightly Toxic	> 10 to 100
Insignificant Toxicity	> 100 to 1000
Relatively Harmless	> 1000

* EL_{50}: The loading of water accommodated fraction causing 50% immobilization of *Daphnia magna* after 48 hours exposure.

8.2 Results

Several attempts to perform the aquatic toxicity test according to OECD 202 were unsuccessful. This test can be done easily with liquid samples, but greases were hard to dissolve in water even when applied to filter papers and placed in the sample water. The test did not produce any repeatable data. Previous tests of liquid lubricants at UNI-NABL Center have been performed successfully using this method. But, in several attempts, the test specimens died as a result of getting stuck to the grease which would separate from the filter paper and clump up on top of the test samples. Due to lack of time, other remedies could not be tried.

8.3 Conclusions

Since the bio-based oils used to make these bio-based greases have generally been shown to be aquatically non-toxic using the daphnia test method in previous effort, the resulting bio-based grease being made of soap and oil could also prove to be non-toxic. Future research should focus on developing a method to dissolve the grease in the test sample for daphnia, or use other tests that use larger species such as fish to test the aquatic toxicity of bio-based greases.

9. Plant Toxicity Tests

Testing the plant toxicity of bio-based greases and lubricants has been an on-going activity at the UNI-NABL Center. It is important to show that well performing bio-based grease can also be bio-based, biodegradable, and non-toxic to plants.

9.1 Test Method

The test method used for plant toxicity was the OECD 208: Terrestrial Plant Test: Seedling Emergence and Seedling Growth Test. In this test standard, seeds are grown in a controlled environment. The emergence and plant shoot are measured and compared. To be considered non-toxic to the test plant, the sample with the product being tested should show growth equal to or greater than 50 percent of the growth of the reference plant having plant food.

9.2 Results

The following table shows the results of the plant toxicity testing for the selected samples. All the sample greases, including the mineral oil-based and bio-based greases, passed this test, which suggests that perhaps a more sensitive test would be needed to differentiate between a product that could impact the plant growth and one benign to the plants.

10. Research Conclusion and Discussion

A comprehensive comparative evaluation of mineral oil-based and bio-based greases was performed in this research effort that studied the feasibility of using bio-based lubricants and greases in railroad applications. Laboratory testing provided a large body of data on the performance of six bio-based and five mineral oil-based greases. Results of testing in a controlled environmental chamber correlate with the field and laboratory results. Additionally, researchers explored a new method of assessing grease tackiness.

The research results indicate that bio-based greases showed a higher extreme pressure performance, which is an important property for heavy loads carried by freight trains.

Bio-based greases proved to be biodegradable and to contain a large amount of bio-based content exceeding the minimum content requirement for USDA bio-based labeling.

The bio-based greases tested in this effort were shown to have comparable or better flowability at extreme cold temperatures. Tested side by side, the bio-based greases carried down the track to the same distances as the mineral oil-based greases with similar performance in terms of carry.

Bio-based greases were shown to perform well in controlled environments as well as in the field. Some of the tested bio-based greases contained a high percentage of renewable carbon and were determined to be biodegradable. But, it appears that the addition of chemical performance additives caused these greases to perform as well as the mineral oil-based greases in some cases.

The results presented here provide a good foundation for industrial users to review and use to select bio-based products based on desired performance criteria.

11. Bibliography

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM D 5864 Test Method for Determining Aerobic Aquatic Biodegradation of Lubricants or Their Components

ASTM D 6081 Practice for Aquatic Toxicity Testing of Lubricants: Sample Preparation and Results Interpretation

ASTM D 6139 Test Method for Determining the Aerobic Aquatic Biodegradation of Lubricants or Their Components Using the Gledhill Shake Flask

ASTM D 6186 Test Method for Oxidation Induction Time of Lubricating Oils by Pressure Differential Scanning Calorimetry (PDSC)

ASTM D 93 Test Method for Flash Point by Penskey-Martens Closed Cup Tester

ASTM D 92 Test Method for Flash and Fire Points by Cleveland Open Cup Tester (DoD adopted)

ASTM D 5558 Test Methods for Determination of the Saponification Number of Fats and Oils

ASTM D 97 Test Method for Determination of Pour Point of Petroleum Products (DoD adopted)

ASTM D 130 Test Method for Corrosiveness to Copper from Petroleum Products by the Copper Strip Tarnish Test (DoD adopted)

ASTM D 4172 Test Method for Wear Preventive Characteristics of Lubricating Fluid (Four-Ball Method) (DoD adopted)

ASTM D 4177 Standard Practice for Automatic Sampling of Petroleum and Petroleum Products (DoD adopted)

ASTM D 5864 Test Method for Determination of Aerobic Aquatic Biodegradation of Lubricants or Their Components

ASTM D 471 Test Method for Elastomer Compatibility of Lubricating Greases and Fluids. The tests involve immersing the sample material in the test fluid and specific temperatures for given periods of time and then checking the test specimen for:

Change in Mass
Change in Volume

Change in Tensile Strength
Change in Hardness

ASTM D 4048 Test Method for Detection of Copper Corrosion from Lubricating Grease. A polished copper strip is immersed in a quantity of test product and heated 10 100 degrees C for 24 hours. Strips are rated based on change in color against standards.

ASTM D130 Test Method for Corrosiveness to Copper from Petroleum Products by Copper Strip Test.

OECD SECTION 2 - EFFECTS ON BIOTIC SYSTEMS -- Ecotoxicology

OECD 201 Alga, Growth Inhibition Test

OECD 202 *Daphnia* sp. Acute Immobilization Test (adopted as *Daphnia* sp.14-day Reproduction Test including an Acute Immobilization Test)

OECD 203 Fish, Acute Toxicity Test

OECD 204 Fish, Prolonged Toxicity Test Study

OECD 205 Avian Dietary Toxicity Test

OECD 206 Avian Reproduction Test

OECD 207 Earthworm, Acute Toxicity Tests

OECD 208 Terrestrial Plants, Growth Test

OECD 209 Activated Sludge, Respiration Inhibition Test

OECD 210 Fish, Early-Life Stage Toxicity Test

OECD 215 Fish, Juvenile Growth Test

OECD 216 Soil Microorganisms: Nitrogen Transformation Test

OECD 217 Soil Microorganisms: Carbon Transformation Test

OECD 222 Earthworm Reproduction Test (*Eisenia fetida/Eisenia andrei*)

OECD 224 Determination of the activity of anaerobic bacteria - reduction of gas production from anaerobically sewage sludge

OECD 227 Terrestrial Plant Test: Vegetative Vigor Test

OECD SECTION 3 - DEGRADATION AND ACCUMULATION

OECD 301 Ready Biodegradability

OECD 301A : DOC Die-Away Test

OECD 301B : Co2 Evolution Test

OECD 301C : Modified MITI Test (I)

OECD 301D : Closed Bottle Test

OECD 301E : Modified OECD Screening Test

OECD 301F : Manometric Respirometry Test

OECD 304A: Inherent Biodegradability in Soil

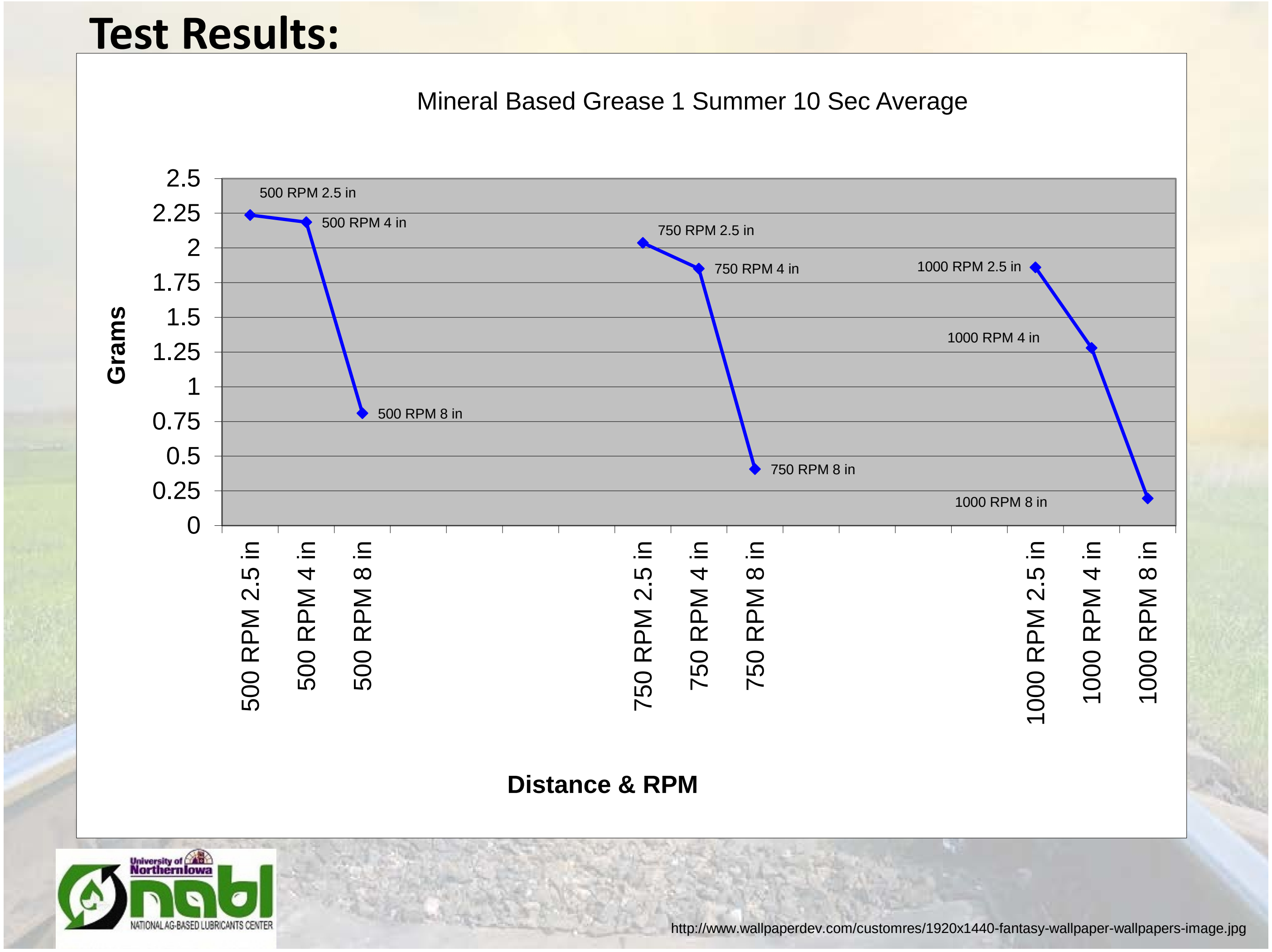
OECD 306 Biodegradability in Seawater

OECD 307 Aerobic and Anaerobic Transformation in Soil

OECD 310 Ready Biodegradability **–** CO_2 in sealed vessels (Headspace Test)

OECD 311 Anaerobic Biodegradability of Organic Compounds in Digested Sludge: by Measurement of Gas Production

Appendix A.
Continuation Test of Adhesion and Cohesion – Grease Tackiness



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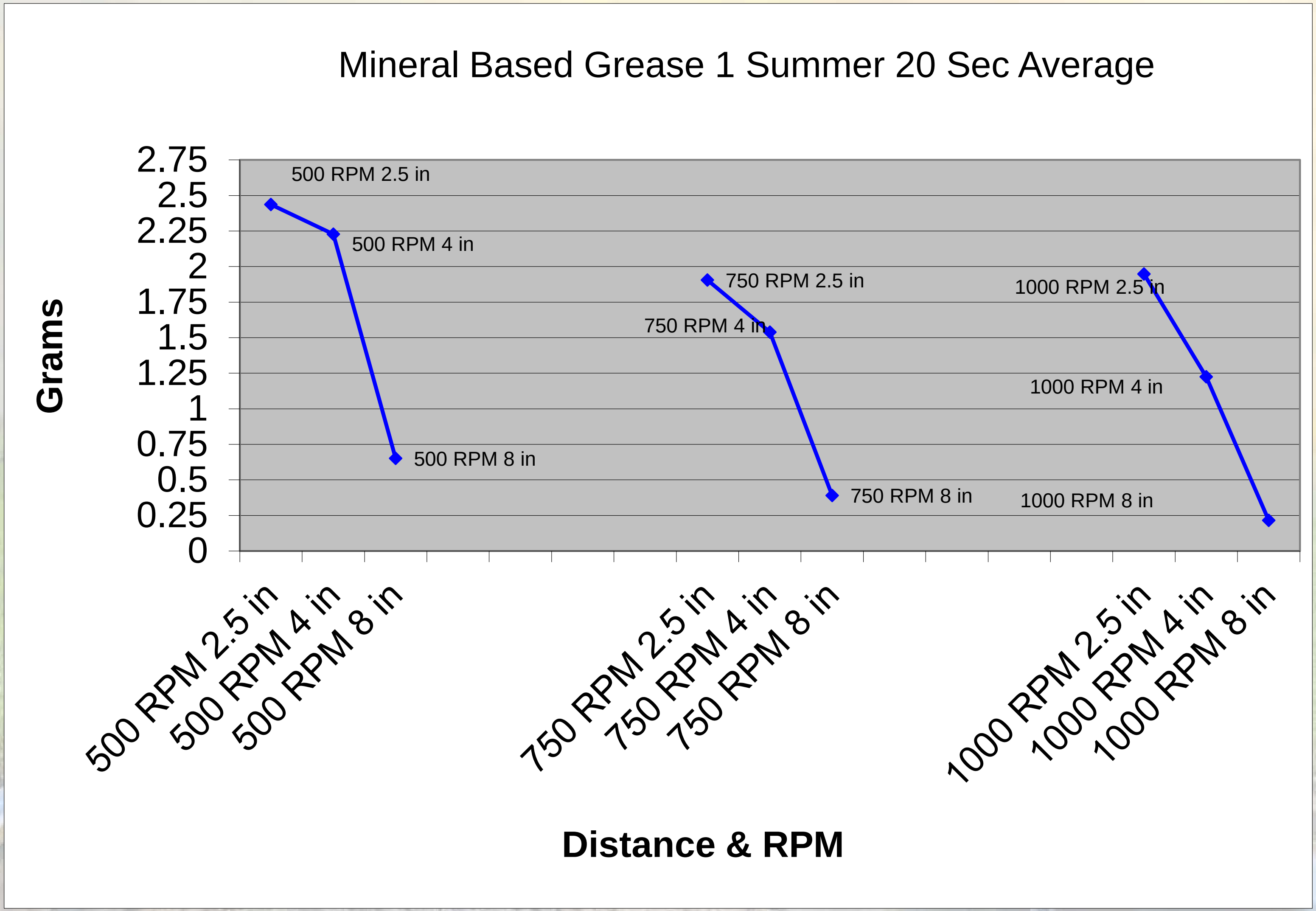

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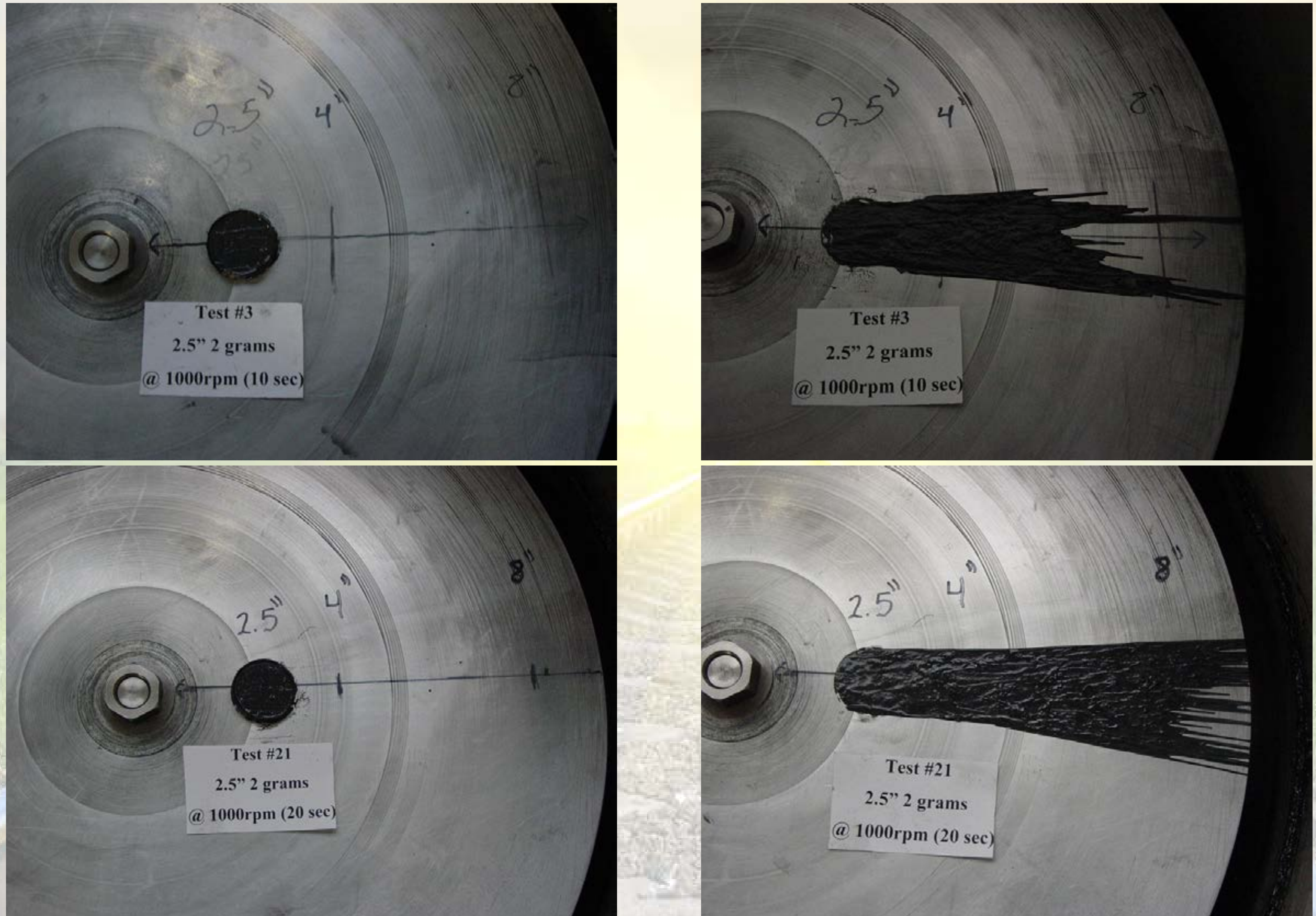
Test Results: Mineral Based Grease 1 Summer



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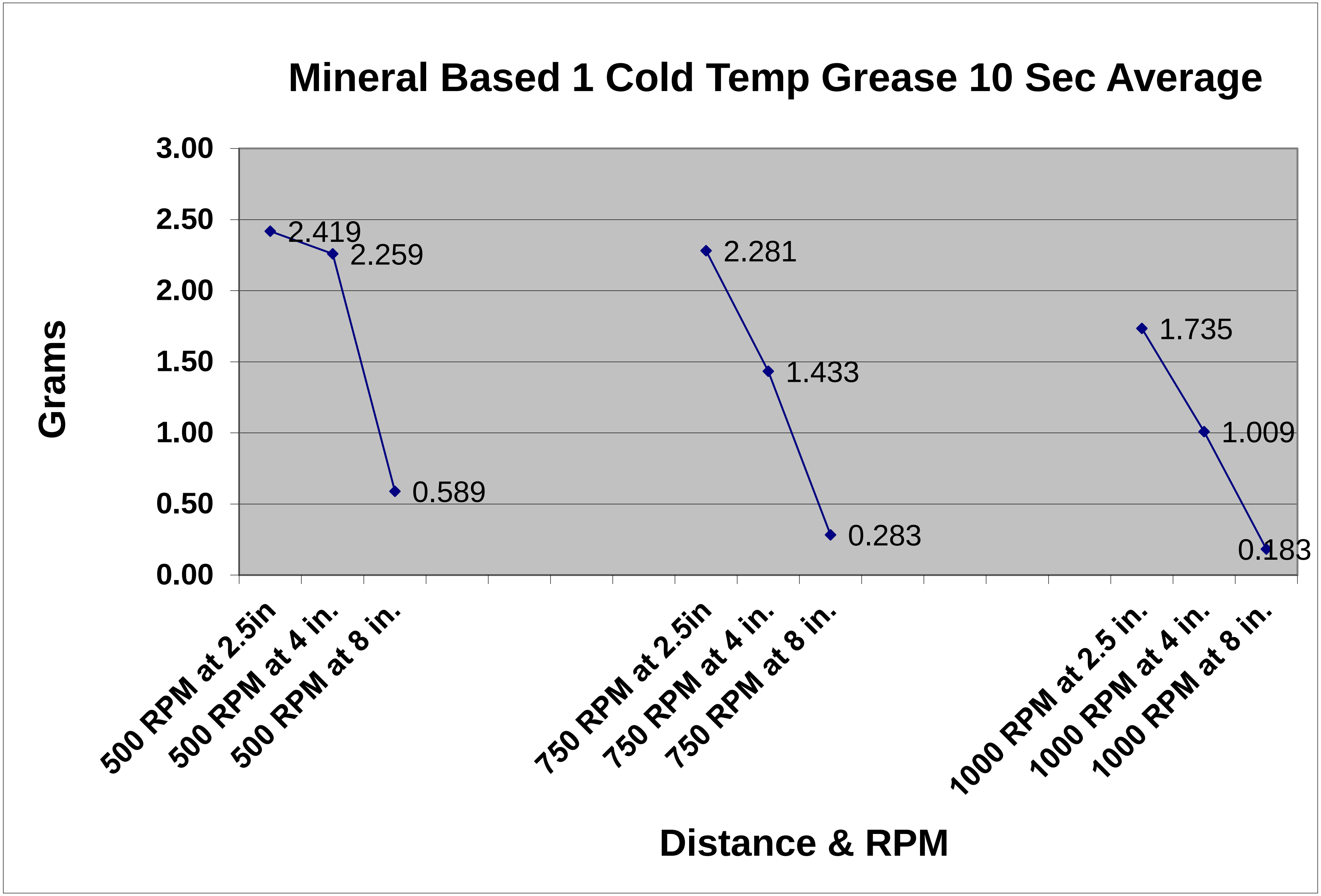
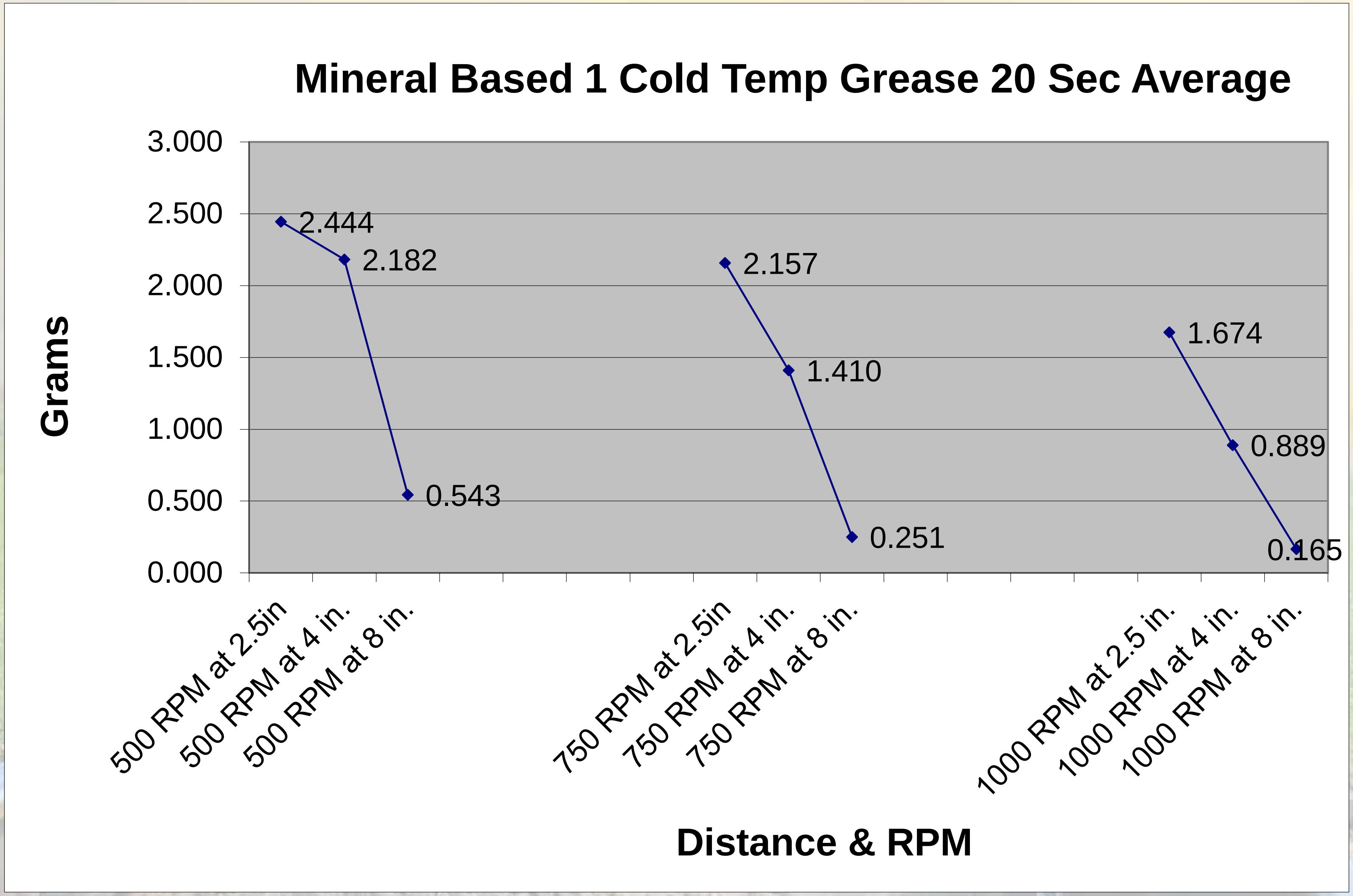

Mineral Based 1 Cold Temp Grease 10 Sec Average
Grams
3.00
2.50
2.00
1.50
1.00
0.50
0.00
2.419
2.259
0.589
2.281
1.433
0.283
1.735
1.009
0.183
500 RPM at 2.5in
500 RPM at 4 in.
500 RPM at 8 in.
750 RPM at 2.5in
750 RPM at 4 in.
750 RPM at 8 in.
1000 RPM at 2.5 in.
1000 RPM at 4 in.
1000 RPM at 8 in.
Distance & RPM

Test Results:



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Test Results: Mineral Based 1 Cold Temp Grease

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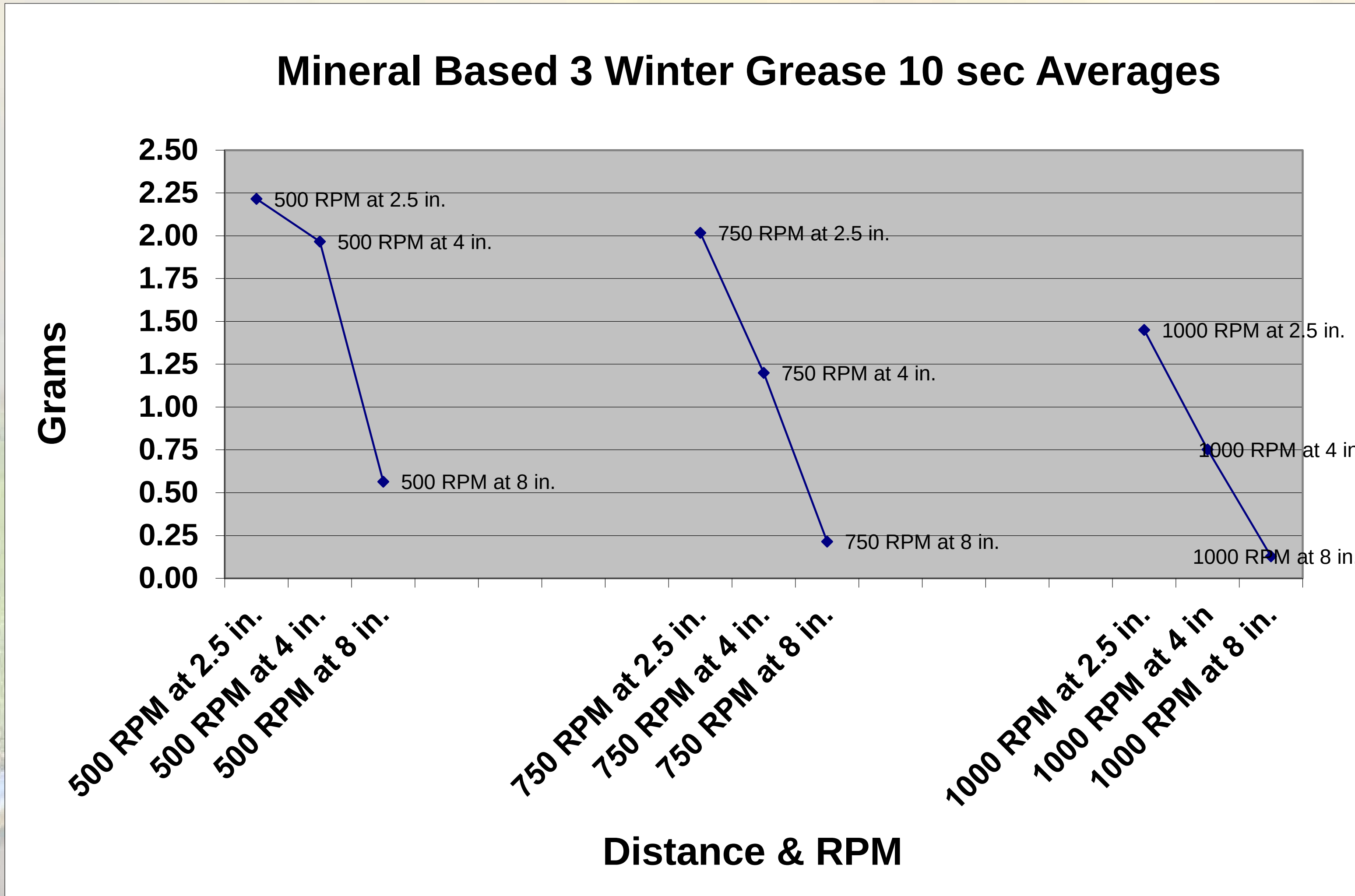
Test Results:



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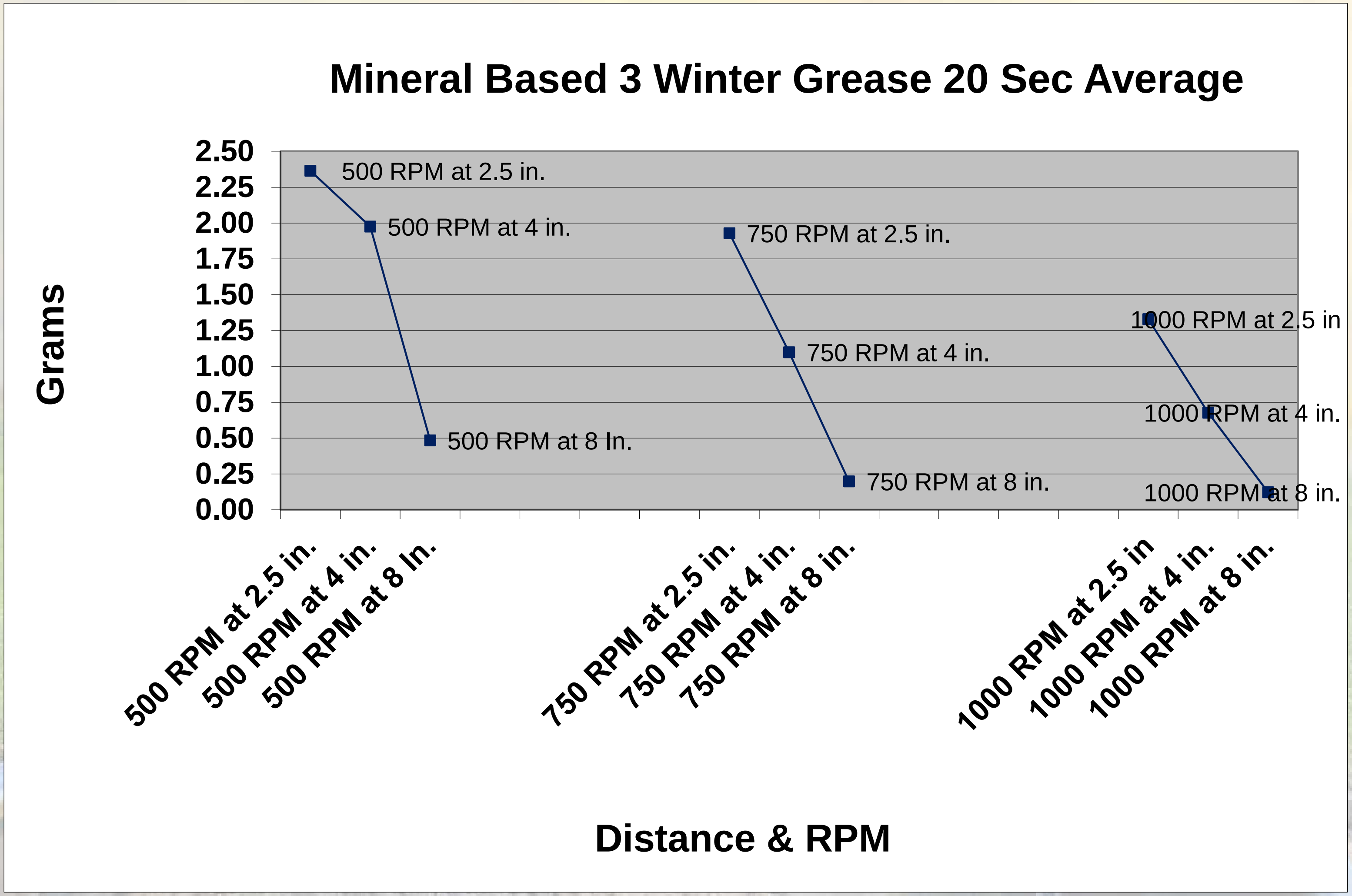
Test Results:



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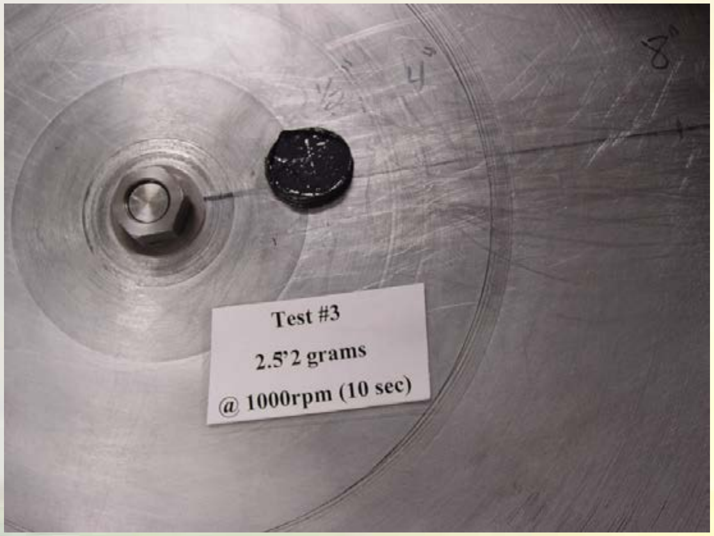
Test Results: Mineral Based 3 Winter Grease



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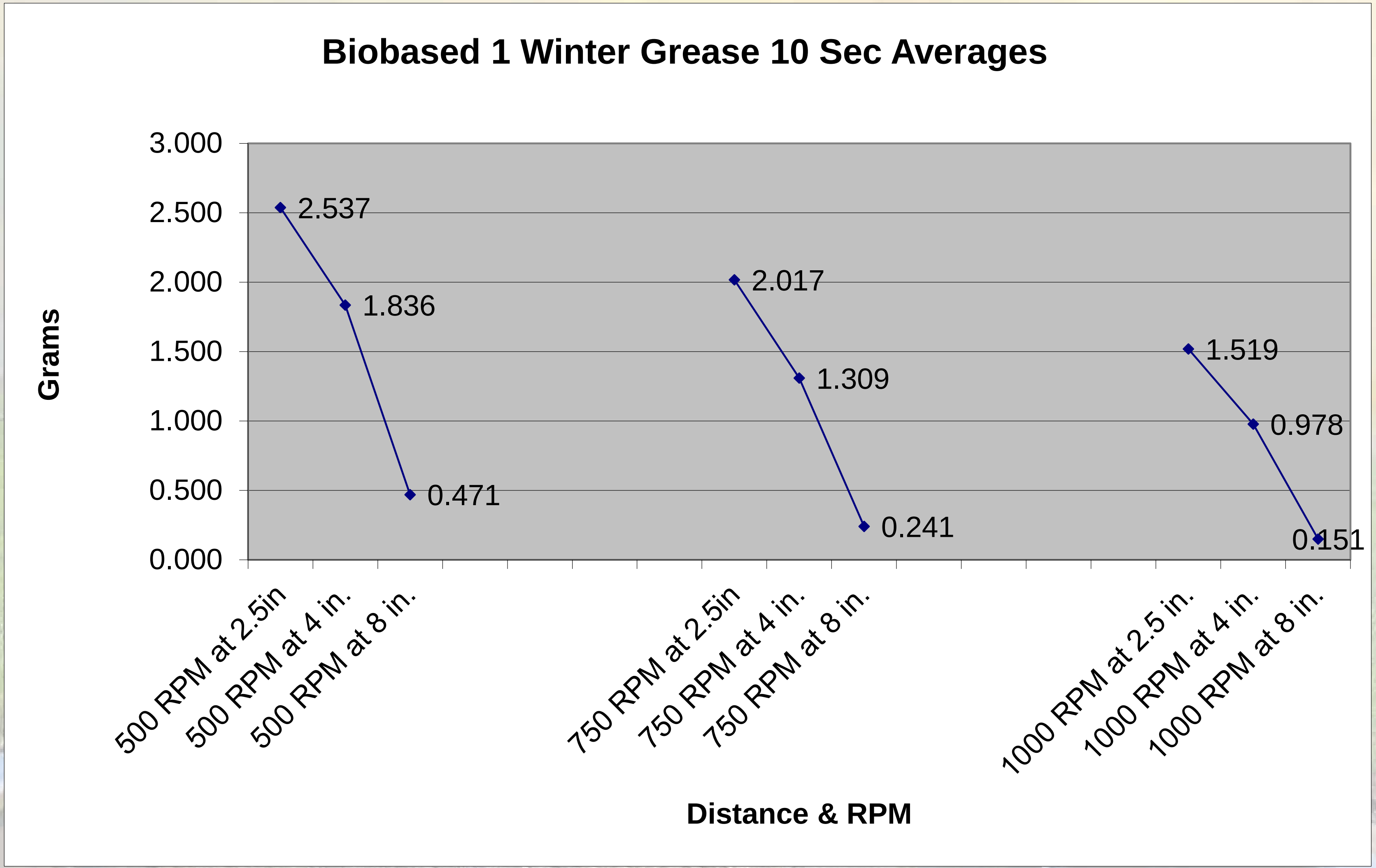

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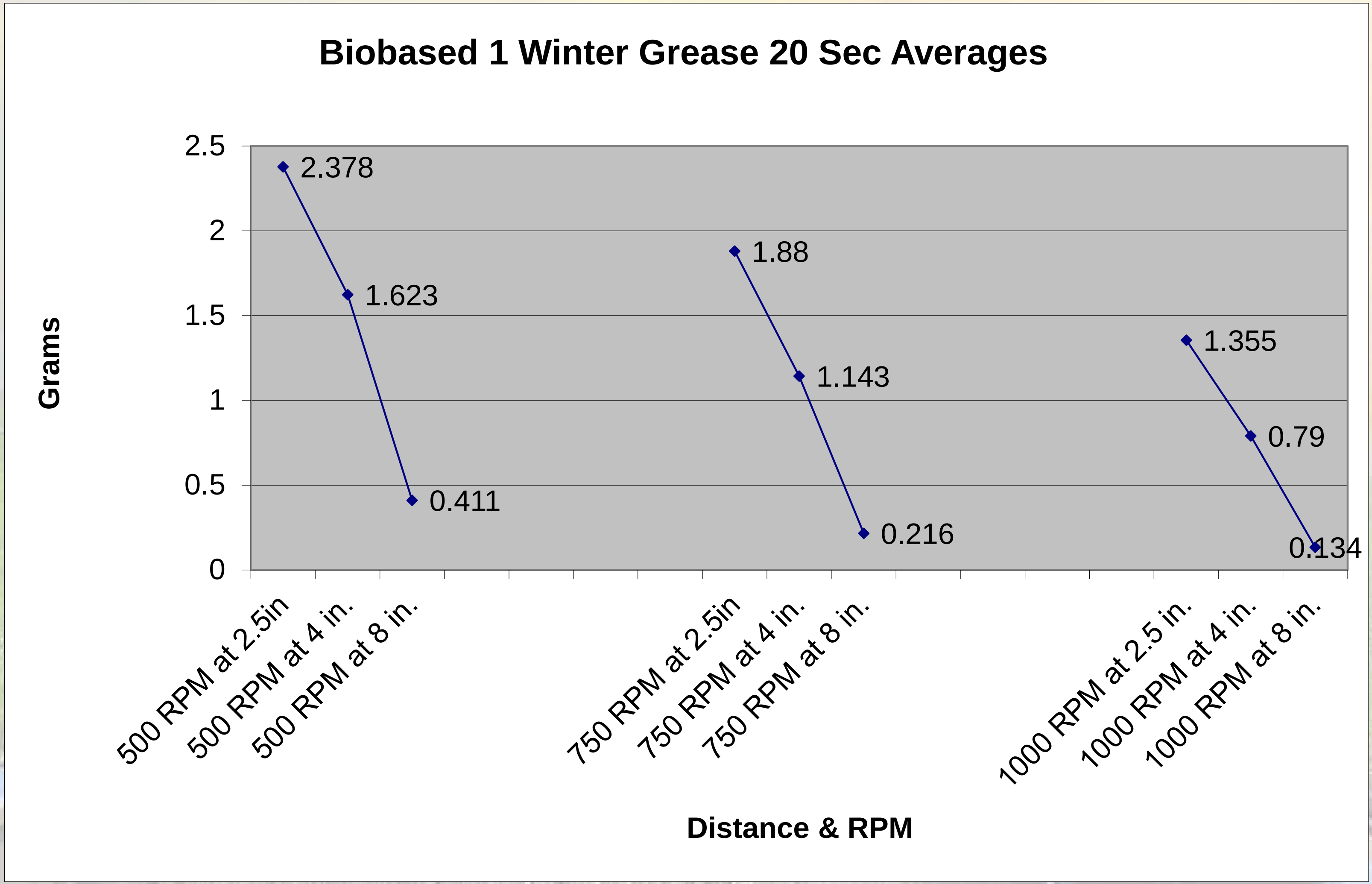

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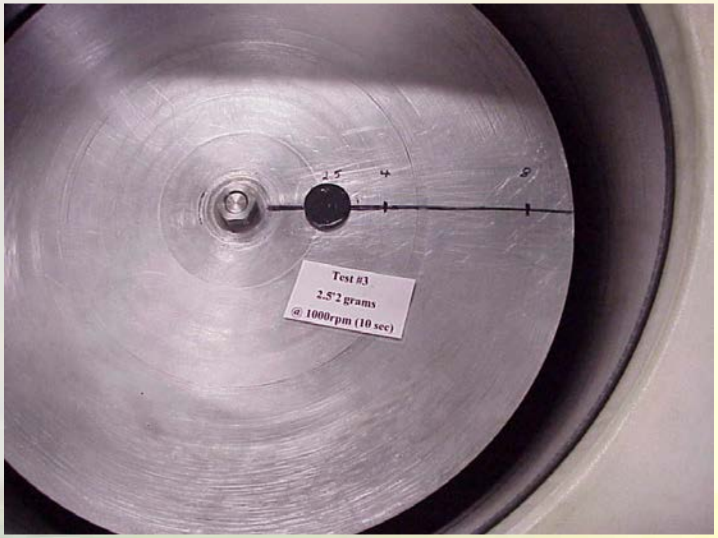
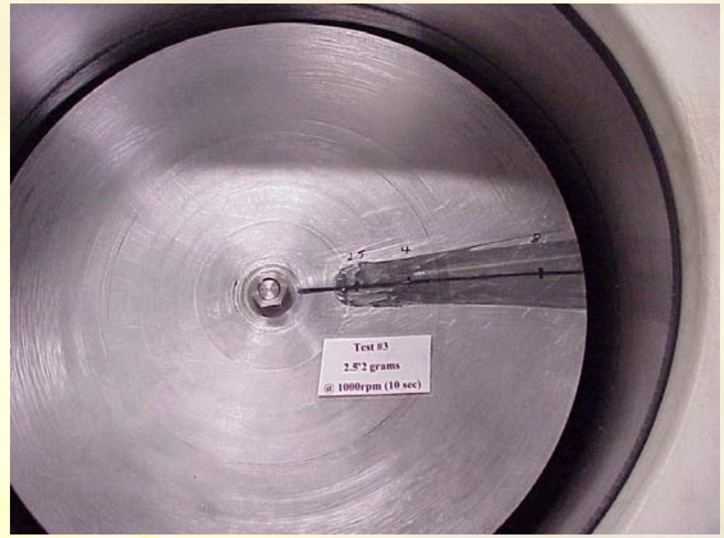
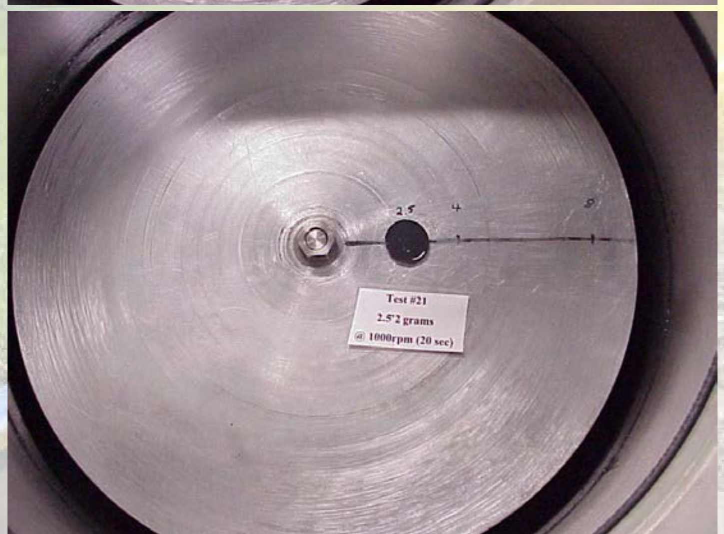
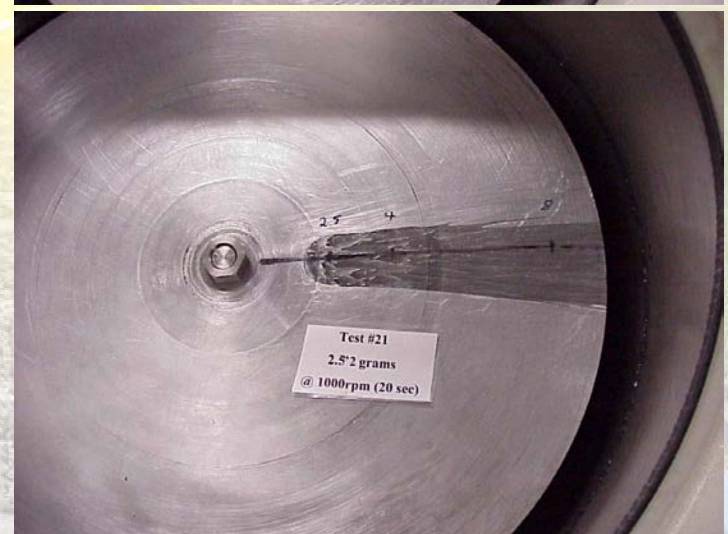
Test Results: Biobased 1 Winter Grease









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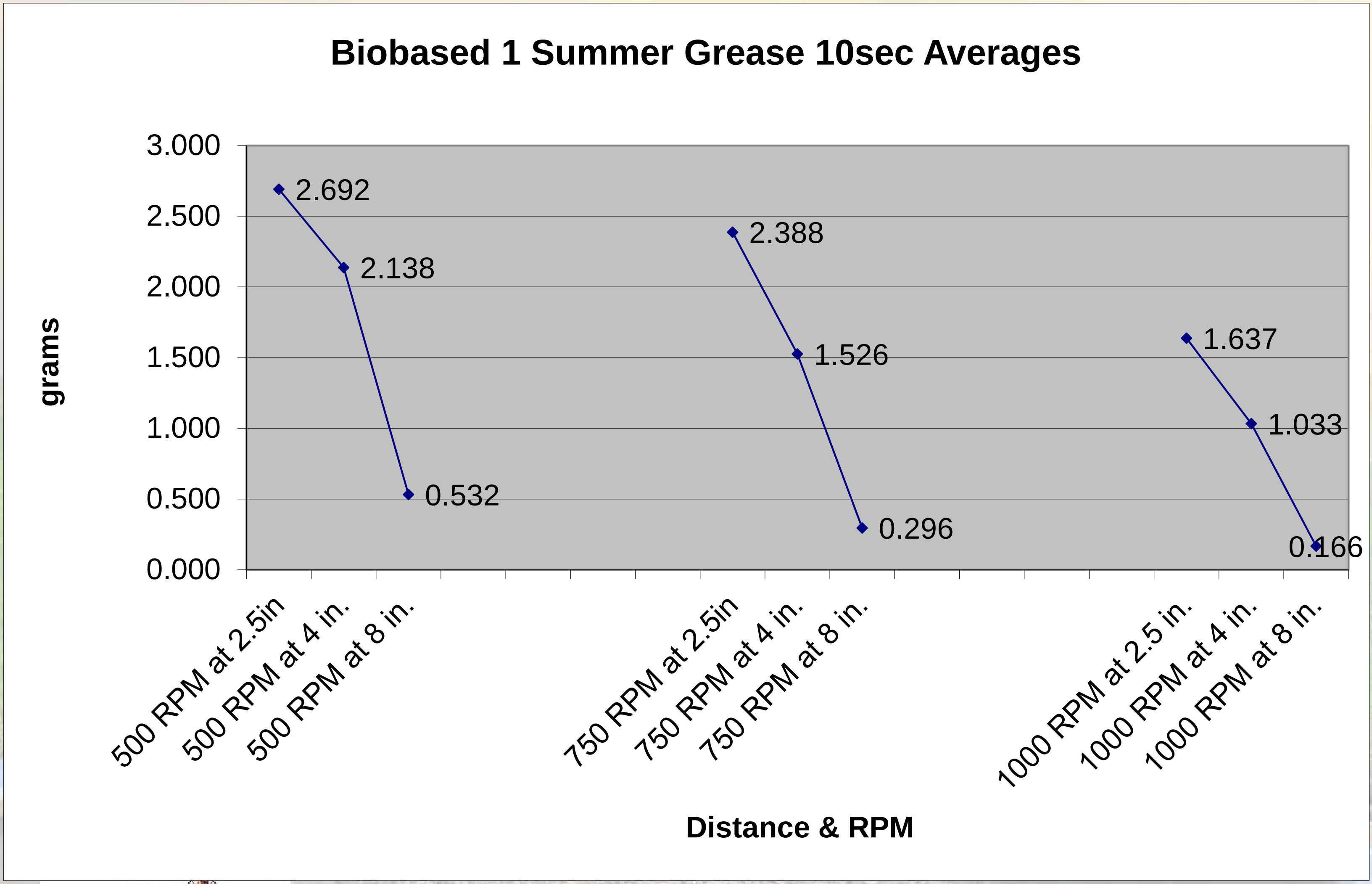

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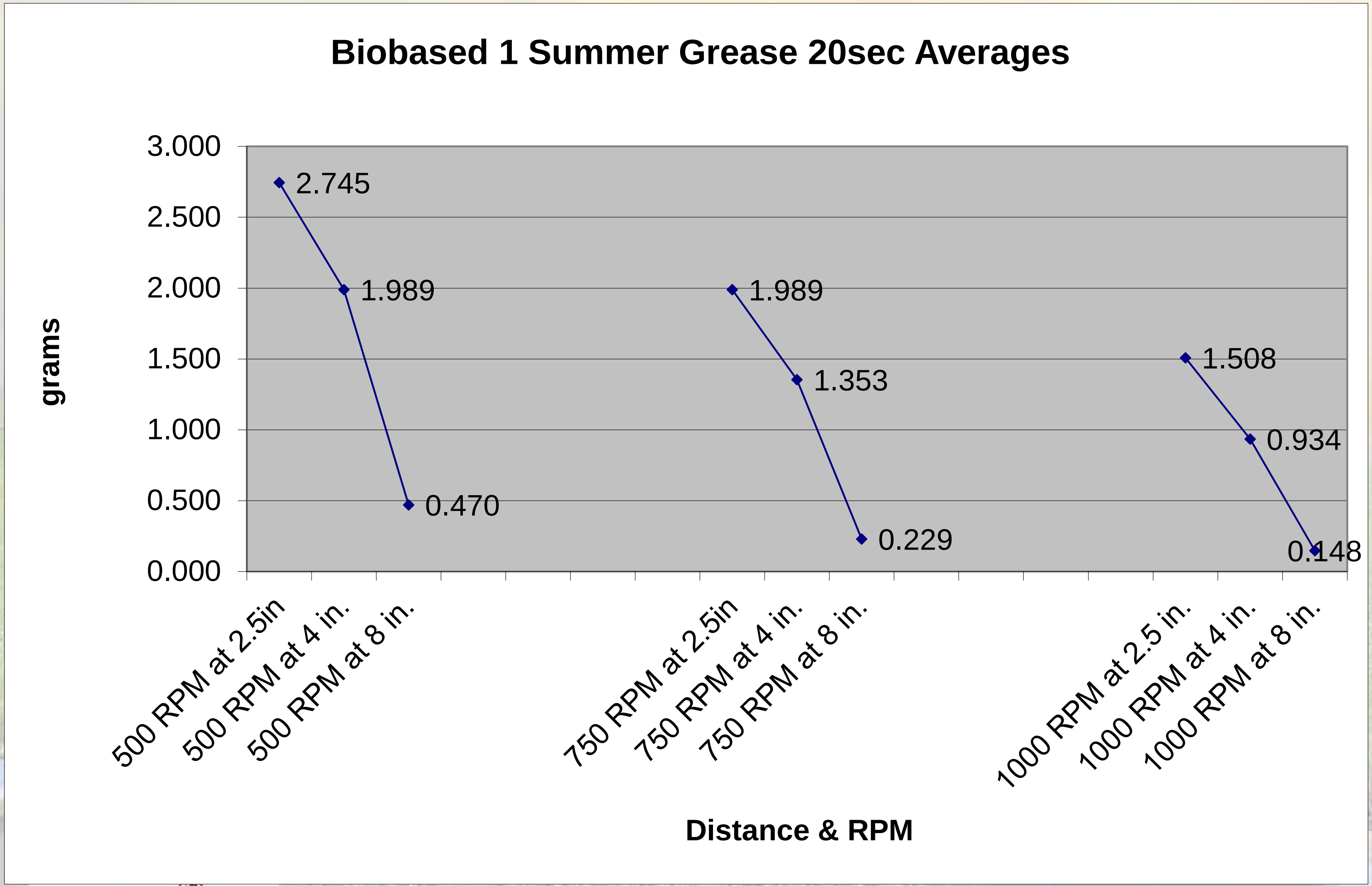

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Test Results: Biobased 1 Summer Grease

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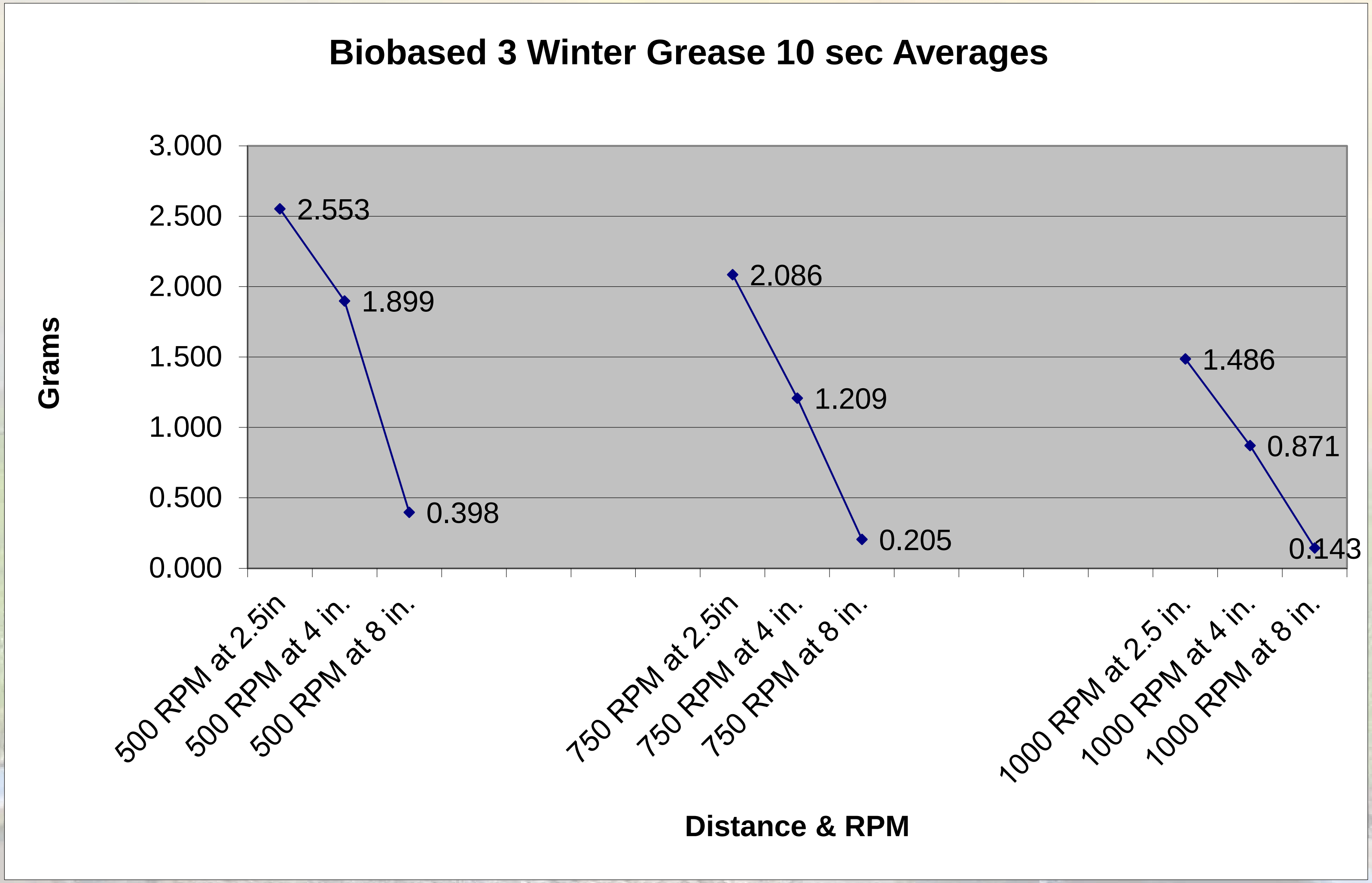
Test Process



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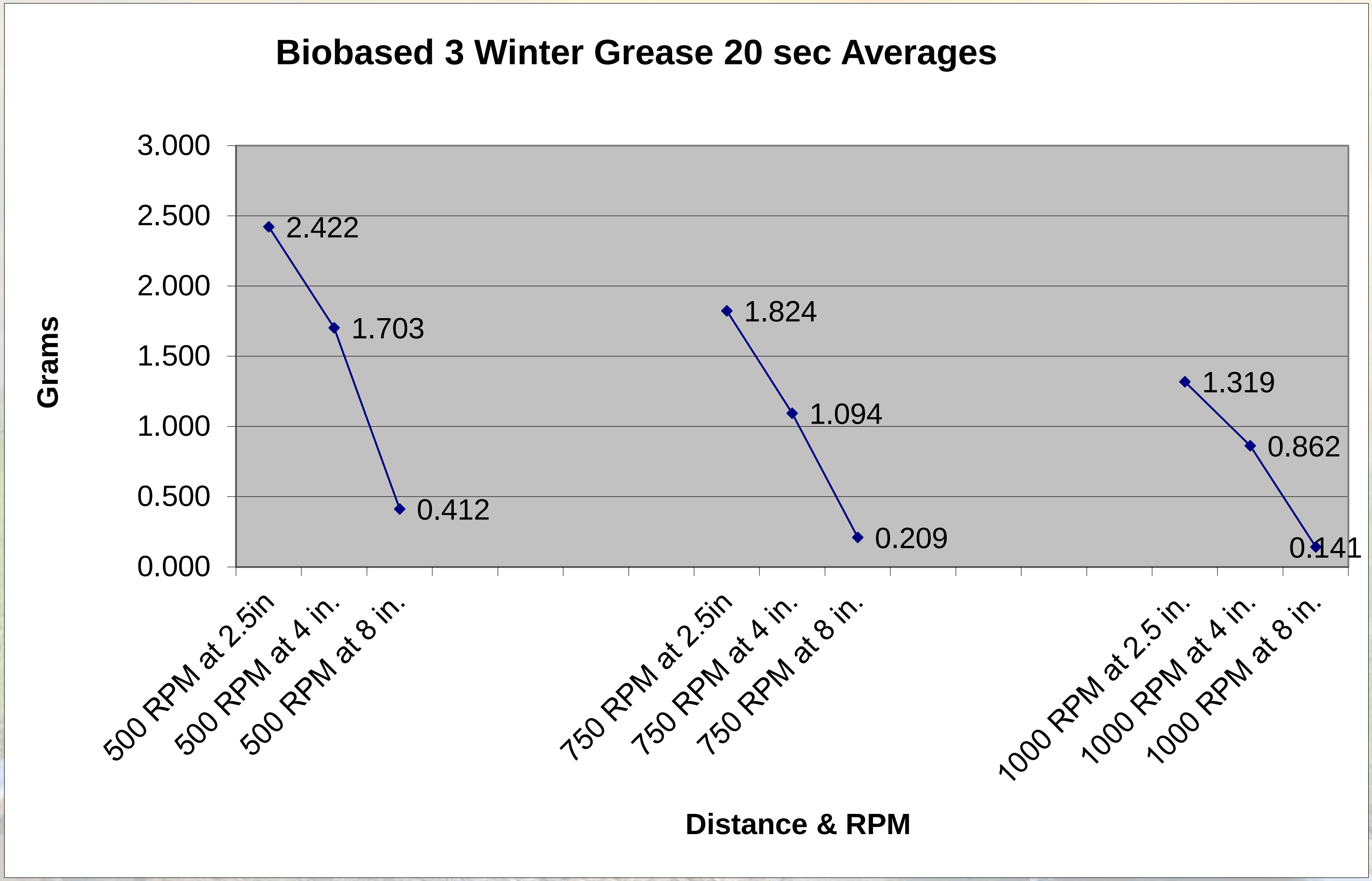

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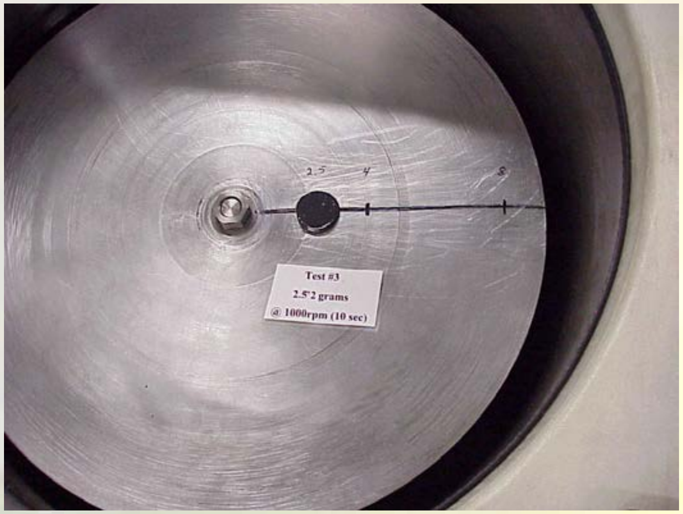
Test Results: Biobased 3 Winter Grease



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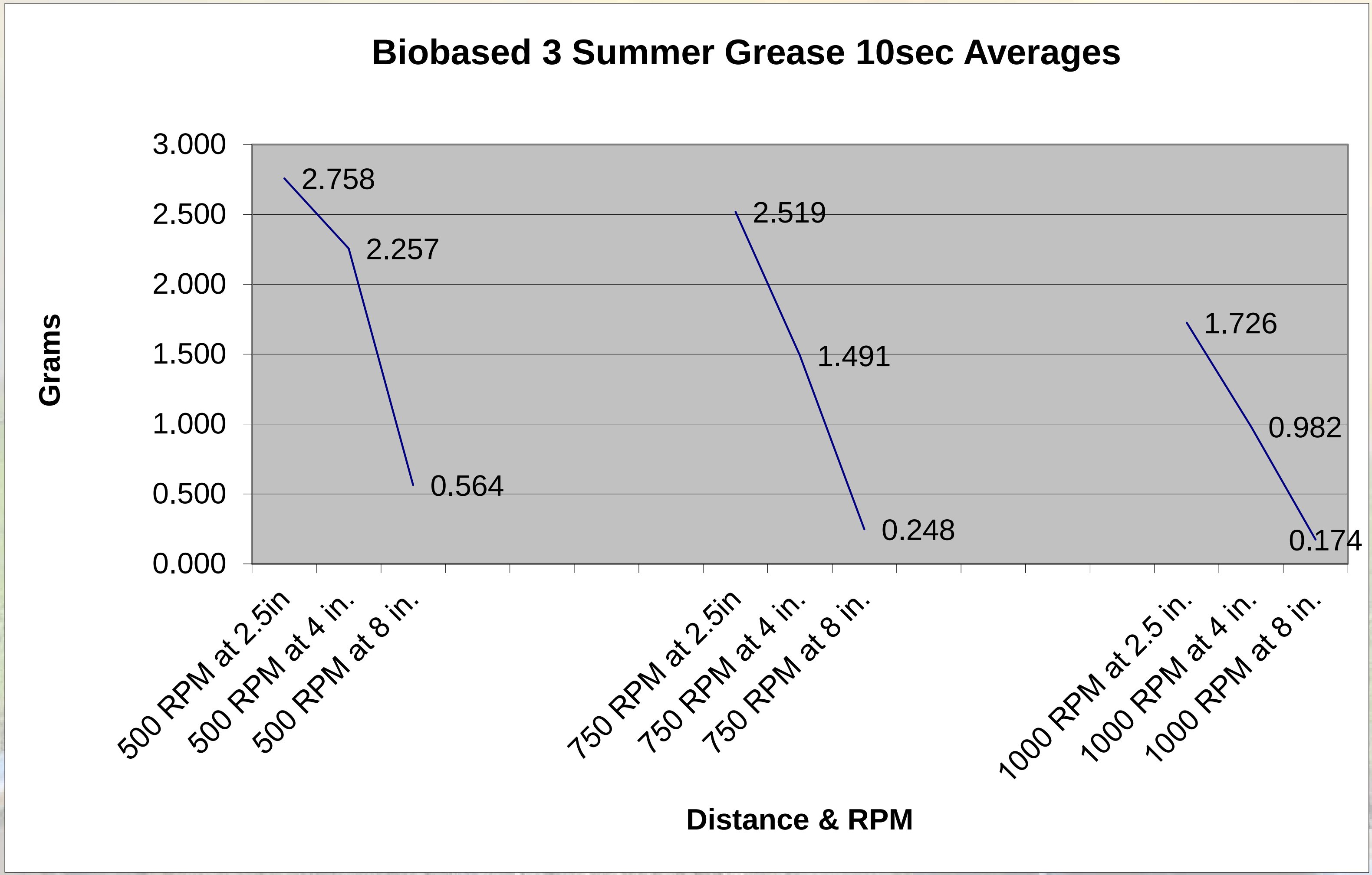

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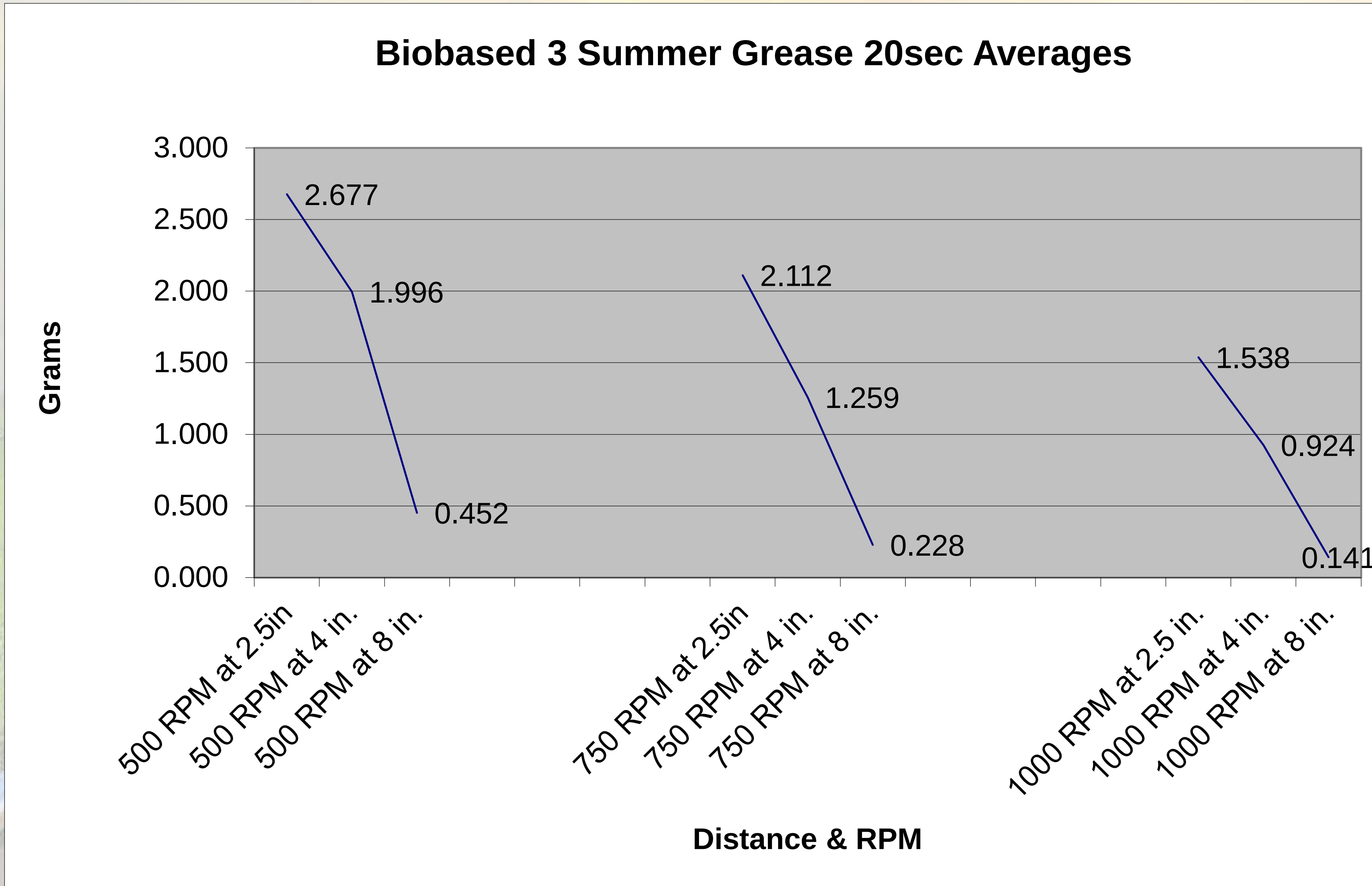

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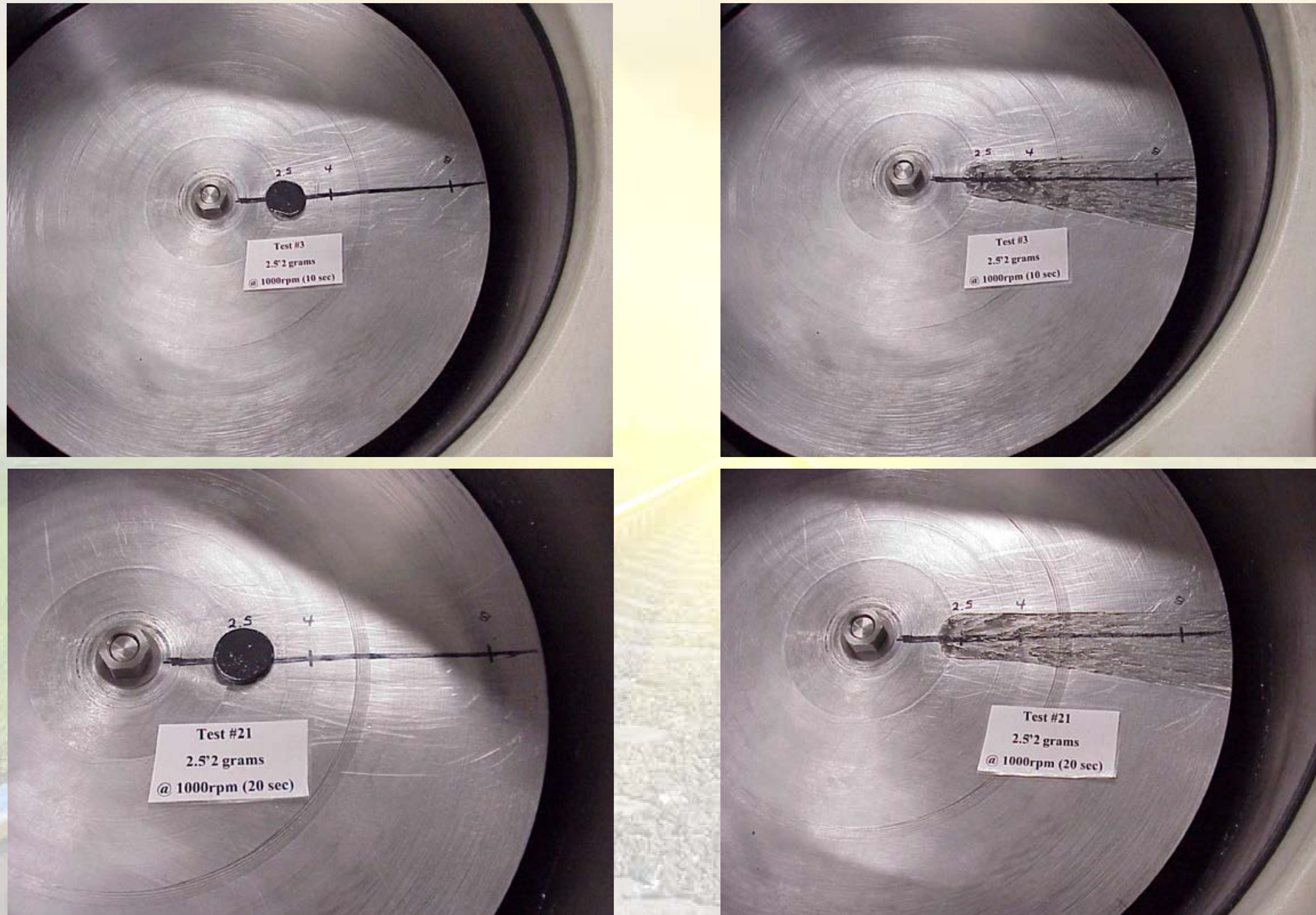
Test Results: Biobased 3 Summer Grease



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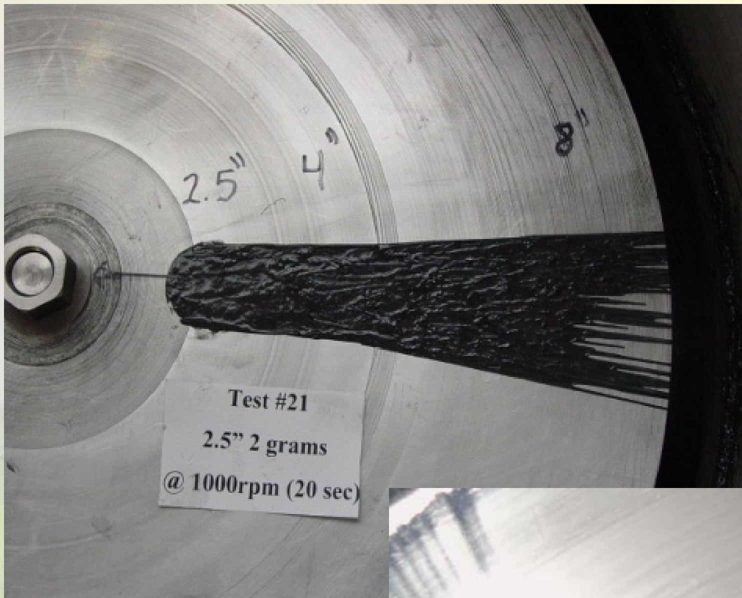

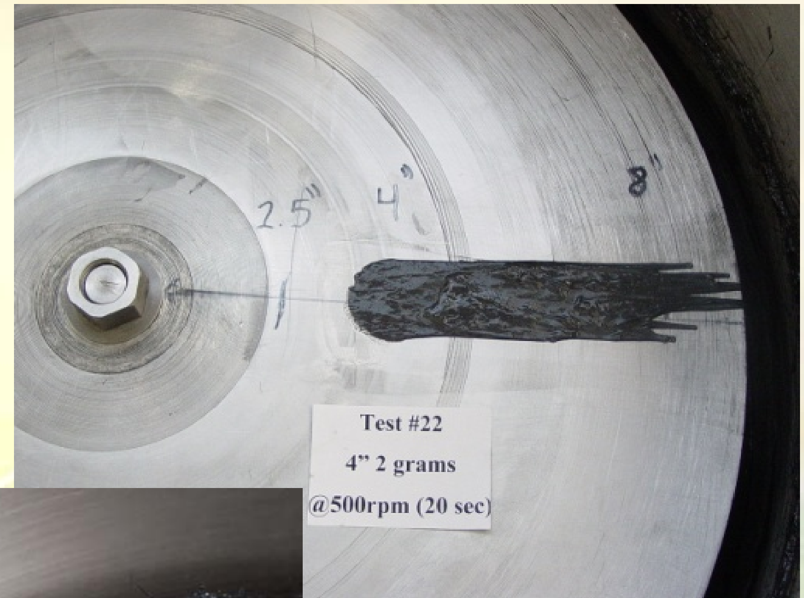

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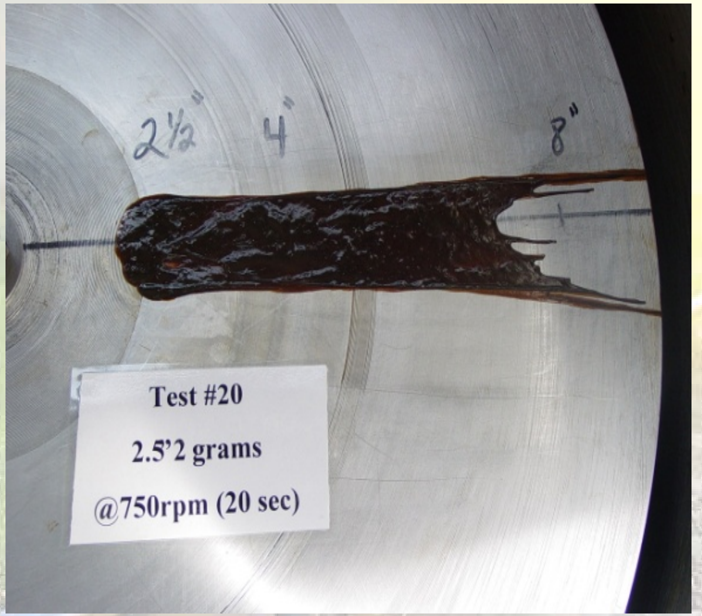

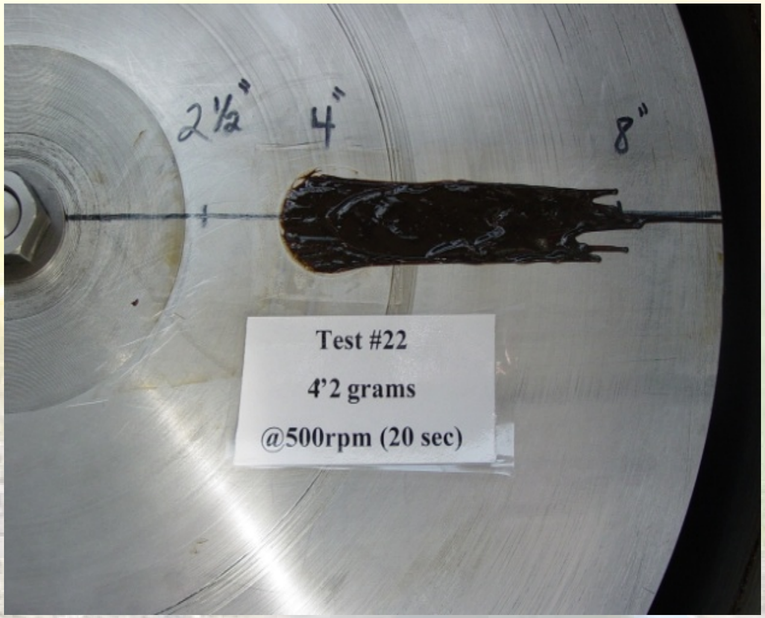

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Test Process

Biobased 2 Grease Winter

Date: Jan 2013

Operator: ---

Grease Quantity: 2.5 grams +/- .3 grams

Time 20 sec.

RPM	500				
	Trial 1	Trial 2	Trial 3		Biobased 2 Grease Winter 20 Sec Average
Distance					
2.5	2.693	2.708	2.658	500 RPM 2.5 in	2.6863333
4	2.633	2.556	2.591	500 RPM 4 in	2.5933333
8	0.821	0.742	0.811	500 RPM 8 in	0.7913333

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Test Process

Biobased 2 Summer Grease

Date: 12-Jun-13

Operator: Darren Keppy

Grease Quantity: 2 grams +/- .6 grams

Time	10 sec.				
RPM	500				
	Trial 1	Trial 2	Trial 3		Averages
Distance					
2.5	2.951	2.95	2.88	500 RPM at 2.5in	2.927
4	2.435	2.681	2.691	500 RPM at 4 in.	2.602
8	0.818	0.572	0.755	500 RPM at 8 in.	0.715
RPM	750				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	2.308	2.549	2.641	750 RPM at 2.5in	2.499
4	1.899	1.399	1.808	750 RPM at 4 in.	1.702
8	0.397	0.576	0.368	750 RPM at 8 in.	0.447
RPM	1000				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	1.948	2.121	2.108	1000 RPM at 2.5 in.	2.059
4	1.427	1.476	1.302	1000 RPM at 4 in.	1.402
8	0.276	0.272	0.297	1000 RPM at 8 in.	0.282

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Test Process

Biobased 2 Summer Grease

Date: 12-Jun-13

Operator: Darren Keppy

Grease Quantity: 2 grams +/- .6 grams

Time 20 sec.

RPM	500				
	Trial 1	Trial 2	Trial 3		Averages
Distance					
2.5	2.931	2.946	2.874	500 RPM at 2.5in	2.917
4	1.823	2.801	2.721	500 RPM at 4 in.	2.448
8	0.628	0.588	0.599	500 RPM at 8 in.	0.605
RPM	750				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	2.301	2.655	2.665	750 RPM at 2.5in	2.540
4	1.877	2.08	1.956	750 RPM at 4 in.	1.971
8	0.399	0.474	0.517	750 RPM at 8 in.	0.463
RPM	1000				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	2.404	2.414	2.525	1000 RPM at 2.5 in.	2.448
4	1.673	1.525	1.552	1000 RPM at 4 in.	1.583
8	0.286	0.31	0.326	1000 RPM at 8 in.	0.307

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Test Process

Mineral Based 2 Winter Grease

Date: Jun-13

Operator: Darren Keppy

Grease Quantity: 2 grams +/- .6 grams

Time 20 sec.

RPM	500				
	Trial 1	Trial 2	Trial 3		Averages
Distance					
2.5	2.465	2.577	2.464	500 RPM at 2.5in	2.502
4	1.804	2.011	1.901	500 RPM at 4 in.	1.905
8	0.358	0.393	0.312	500 RPM at 8 in.	0.354
RPM	750				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	1.9	1.601	1.542	750 RPM at 2.5in	1.681
4	0.936	0.959	0.895	750 RPM at 4 in.	0.930
8	0.157	0.159	0.152	750 RPM at 8 in.	0.156
RPM	1000				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	1.244	1.048	1.165	1000 RPM at 2.5 in.	1.152
4	0.656	0.634	0.586	1000 RPM at 4 in.	0.625
8	0.082	0.081	0.094	1000 RPM at 8 in.	0.086

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Test Process

Mineral Based 2 Summer Grease					
Date:	3-Jul-13				
Operator:	Darren Keppy				
Grease Quantity: 2 grams +/- .6 grams					
Time	20 sec.				
RPM	500				
	Trial 1	Trial 2	Trial 3		Averages
Distance					
2.5	2.477	2.488	2.394	500 RPM at 2.5in	2.453
4	1.678	1.581	1.501	500 RPM at 4 in.	1.587
8	0.41	0.368	0.379	500 RPM at 8 in.	0.386
RPM	750				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	1.727	1.927	1.667	750 RPM at 2.5in	1.774
4	1.083	1.039	1.018	750 RPM at 4 in.	1.047
8	0.167	0.181	0.167	750 RPM at 8 in.	0.172
RPM	1000				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	1.235	1.213	1.116	1000 RPM at 2.5 in.	1.188
4	0.775	0.758	0.716	1000 RPM at 4 in.	0.750
8	0.102	0.112	0.114	1000 RPM at 8 in.	0.109

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Test Process

Mineral Based Grease 1 Summer

Date: Jan. 2013

Operator: Brendon Good, Greg Moklestad

Grease Quantity: 2 grams +/- 0.6

Time	10 sec.				
RPM	500				
	Trial 1	Trial 2	Trial 3		Averages
Distance					
2.5	2.45	2.13	2.13	500 RPM 2.5 in	2.2366667
4	2.2	2.2	2.156	500 RPM 4 in	2.1853333
8	0.703	0.918	0.809	500 RPM 8 in	0.81
RPM	750				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	2.15	1.99	1.97	750 RPM 2.5 in	2.0366667
4	1.875	1.99	1.69	750 RPM 4 in	1.8516667
8	0.46	0.356	0.408	750 RPM 8 in	0.408
RPM	1000				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	1.98	1.72	1.88	1000 RPM 2.5 in	1.86
4	1.359	1.144	1.339	1000 RPM 4 in	1.2806667
8	0.223	0.187	0.179	1000 RPM 8 in	0.1963333

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Test Process

Mineral Based Grease 1 Summer

Date: Jan. 2013

Operator: Brendon Good, Greg Moklestad

Grease Quantity: 2 grams +/- 0.6

Time	20 sec.				
RPM	500				
	Trial 1	Trial 2	Trial 3		Averages
Distance					
2.5	2.421	2.51	2.38	500 RPM 2.5 in	2.437
4	2.261	2.151	2.271	500 RPM 4 in	2.2276667
8	0.6541	0.6625	0.6374	500 RPM 8 in	0.6513333
RPM	750				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	1.4133	2.1879	2.1172	750 RPM 2.5 in	1.9061333
4	1.41	1.736	1.472	750 RPM 4 in	1.5393333
8	0.3785	0.4369	0.3575	750 RPM 8 in	0.3909667
RPM	1000				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	1.9157	1.9594	1.9702	1000 RPM 2.5 in	1.9484333
4	1.212	1.261	1.2	1000 RPM 4 in	1.2243333
8	0.2269	0.2209	0.2009	1000 RPM 8 in	0.2162333

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Test Process

Mineral Based Grease 1 Summer

Date: Jan. 2013

Operator: Brendon Good, Greg Moklestad

Grease Quantity: 2 grams +/- 0.6

Time	10 sec.				
RPM	500				
	Trial 1	Trial 2	Trial 3		Averages
Distance					
2.5	2.45	2.13	2.13	500 RPM 2.5 in	2.2366667
4	2.2	2.2	2.156	500 RPM 4 in	2.1853333
8	0.703	0.918	0.809	500 RPM 8 in	0.81
RPM	750				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	2.15	1.99	1.97	750 RPM 2.5 in	2.0366667
4	1.875	1.99	1.69	750 RPM 4 in	1.8516667
8	0.46	0.356	0.408	750 RPM 8 in	0.408
RPM	1000				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	1.98	1.72	1.88	1000 RPM 2.5 in	1.86
4	1.359	1.144	1.339	1000 RPM 4 in	1.2806667
8	0.223	0.187	0.179	1000 RPM 8 in	0.1963333

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Test Process

Mineral Based Grease 1 Summer

Date: Jan. 2013

Operator: Brendon Good, Greg Moklestad

Grease Quantity: 2 grams +/- 0.6

Time	20 sec.				
RPM	500				
	Trial 1	Trial 2	Trial 3		Averages
Distance					
2.5	2.421	2.51	2.38	500 RPM 2.5 in	2.437
4	2.261	2.151	2.271	500 RPM 4 in	2.2276667
8	0.6541	0.6625	0.6374	500 RPM 8 in	0.6513333
RPM	750				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	1.4133	2.1879	2.1172	750 RPM 2.5 in	1.9061333
4	1.41	1.736	1.472	750 RPM 4 in	1.5393333
8	0.3785	0.4369	0.3575	750 RPM 8 in	0.3909667
RPM	1000				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	1.9157	1.9594	1.9702	1000 RPM 2.5 in	1.9484333
4	1.212	1.261	1.2	1000 RPM 4 in	1.2243333
8	0.2269	0.2209	0.2009	1000 RPM 8 in	0.2162333

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Test Process

Mineral Based 1 Cold Temp Grease

Date: 2013 May

Operator: Darren Keppy

Grease Quantity: 2 grams +/- .6 grams

Time 10 sec.

RPM	500				
	Trial 1	Trial 2	Trial 3		Averages
Distance					
2.5	2.474	2.378	2.404	500 RPM at 2.5in	2.419
4	2.263	2.251	2.263	500 RPM at 4 in.	2.259
8	0.58	0.563	0.625	500 RPM at 8 in.	0.589
RPM	750				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	2.284	2.277	2.283	750 RPM at 2.5in	2.281
4	1.445	1.389	1.465	750 RPM at 4 in.	1.433
8	0.288	0.275	0.287	750 RPM at 8 in.	0.283
RPM	1000				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	1.872	1.65	1.682	1000 RPM at 2.5 in.	1.735
4	1.081	1.003	0.944	1000 RPM at 4 in.	1.009
8	0.173	0.183	0.193	1000 RPM at 8 in.	0.183

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Test Process

Mineral Based 1 Cold Temp Grease

Date: May-13

Operator: Darren Keppy

Grease Quantity: 2 grams +/- .6 grams

Time 20 sec.

RPM	500				
	Trial 1	Trial 2	Trial 3		Averages
Distance					
2.5	2.397	2.489	2.446	500 RPM at 2.5in	2.444
4	2.227	2.058	2.26	500 RPM at 4 in.	2.182
8	0.541	0.556	0.532	500 RPM at 8 in.	0.543
RPM	750				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	1.965	2.173	2.334	750 RPM at 2.5in	2.157
4	1.335	1.488	1.406	750 RPM at 4 in.	1.410
8	0.279	0.225	0.248	750 RPM at 8 in.	0.251
RPM	1000				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	1.76	1.6	1.663	1000 RPM at 2.5 in.	1.674
4	0.934	0.888	0.846	1000 RPM at 4 in.	0.889
8	0.166	0.159	0.17	1000 RPM at 8 in.	0.165

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Test Process

Mineral Based 3 Winter Grease

Date:	2013 May				
Operator:	Darren Keppy				
Grease Quantity: 2 grams +/- .6 grams					
Time	10 sec.				
RPM	500				
	Trial 1	Trial 2	Trial 3		Averages
Distance					
2.5	2.241	2.204	2.201	500 RPM at 2.5 in.	2.215
4	2.094	1.864	1.941	500 RPM at 4 in.	1.966
8	0.607	0.52	0.567	500 RPM at 8 in.	0.565
RPM	750				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	1.953	2.037	2.061	750 RPM at 2.5 in.	2.017
4	1.129	1.282	1.187	750 RPM at 4 in.	1.199
8	0.206	0.25	0.188	750 RPM at 8 in.	0.215
RPM	1000				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	1.332	1.425	1.595	1000 RPM at 2.5 in.	1.451
4	0.767	0.71	0.78	1000 RPM at 4 in	0.752
8	0.16	0.125	0.098	1000 RPM at 8 in.	0.128

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Test Process

Mineral Based 3 Winter Grease

Date: 2013 May
Operator: Darren Keppy
Grease Quantity: 2 grams +/- .6 grams
Time 20 sec.

RPM	500				
	Trial 1	Trial 2	Trial 3		Averages
Distance					
2.5	2.234	2.503	2.356	500 RPM at 2.5 in.	2.364
4	2.05	1.989	1.886	500 RPM at 4 in.	1.975
8	0.495	0.483	0.473	500 RPM at 8 In.	0.484
RPM	750				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	1.927	1.969	1.889	750 RPM at 2.5 in.	1.928
4	1.117	1.121	1.06	750 RPM at 4 in.	1.099
8	0.203	0.187	0.205	750 RPM at 8 in.	0.198
RPM	1000				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	1.271	1.389	1.327	1000 RPM at 2.5 in	1.329
4	0.641	0.707	0.685	1000 RPM at 4 in.	0.678
8	0.129	0.121	0.117	1000 RPM at 8 in.	0.122

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Test Process

Biobased 1 Winter Grease

Date: 12-Aug-13
Operator: Darren
Grease Quantity: 2 grams +/- .6 grams
Time 10 sec.

RPM	500				
	Trial 1	Trial 2	Trial 3		Averages
Distance					
2.5	2.559	2.483	2.57	500 RPM at 2.5in	2.537
4	1.943	1.765	1.801	500 RPM at 4 in.	1.836
8	0.45	0.477	0.485	500 RPM at 8 in.	0.471
RPM	750				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	2.014	2.142	1.895	750 RPM at 2.5in	2.017
4	1.377	1.266	1.284	750 RPM at 4 in.	1.309
8	0.227	0.243	0.254	750 RPM at 8 in.	0.241
RPM	1000				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	1.475	1.447	1.635	1000 RPM at 2.5 in.	1.519
4	0.998	0.928	1.007	1000 RPM at 4 in.	0.978
8	0.157	0.142	0.153	1000 RPM at 8 in.	0.151

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Test Process

Biobased 1 Winter Grease

Date: 12-Aug-13

Operator: Darren

Grease Quantity: 2 grams +/- .6 grams

Time 20 sec.

RPM	500				
	Trial 1	Trial 2	Trial 3		Averages
Distance					
2.5	2.192	2.515	2.427	500 RPM at 2.5in	2.378
4	1.504	1.744	1.622	500 RPM at 4 in.	1.623
8	0.384	0.431	0.418	500 RPM at 8 in.	0.411
RPM	750				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	1.905	1.916	1.819	750 RPM at 2.5in	1.88
4	1.184	1.147	1.099	750 RPM at 4 in.	1.143
8	0.22	0.211	0.218	750 RPM at 8 in.	0.216
RPM	1000				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	1.277	1.362	1.427	1000 RPM at 2.5 in.	1.355
4	0.767	0.817	0.786	1000 RPM at 4 in.	0.79
8	0.136	0.135	0.132	1000 RPM at 8 in.	0.134

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Test Process

Biobased 1 Summer Grease

Date:	19-Aug-13				
Operator:	Darren				
Grease Quantity: 2 grams +/- .6 grams					
Time	10 sec.				
RPM	500				
	Trial 1	Trial 2	Trial 3		Averages
Distance					
2.5	2.716	2.668	2.691	500 RPM at 2.5in	2.692
4	1.912	2.165	2.338	500 RPM at 4 in.	2.138
8	0.589	0.535	0.471	500 RPM at 8 in.	0.532
RPM	750				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	2.272	2.432	2.461	750 RPM at 2.5in	2.388
4	1.553	1.433	1.591	750 RPM at 4 in.	1.526
8	0.29	0.279	0.319	750 RPM at 8 in.	0.296
RPM	1000				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	1.64	1.669	1.603	1000 RPM at 2.5 in.	1.637
4	1.023	1.045	1.03	1000 RPM at 4 in.	1.033
8	0.171	0.161	0.167	1000 RPM at 8 in.	0.166

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Test Process

Biobased 1 Summer Grease

Date: 19-Aug-13

Operator: Darren

Grease Quantity: 2 grams +/- .6 grams

Time 20 sec.

RPM	500				
	Trial 1	Trial 2	Trial 3		Averages
Distance					
2.5	2.787	2.777	2.671	500 RPM at 2.5in	2.745
4	1.923	2.016	2.029	500 RPM at 4 in.	1.989
8	0.463	0.446	0.502	500 RPM at 8 in.	0.470
RPM	750				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	2.154	1.835	1.977	750 RPM at 2.5in	1.989
4	1.359	1.407	1.294	750 RPM at 4 in.	1.353
8	0.212	0.23	0.245	750 RPM at 8 in.	0.229
RPM	1000				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	1.404	1.575	1.546	1000 RPM at 2.5 in.	1.508
4	0.948	0.909	0.945	1000 RPM at 4 in.	0.934
8	0.144	0.144	0.155	1000 RPM at 8 in.	0.148

Test Process

Biobased 3 Winter Grease

Date: 12-Jul-13

Operator: Darren Keppy

Grease Quantity: 2 grams +/- .6 grams

Time 10 sec.

RPM	500				
	Trial 1	Trial 2	Trial 3		Averages
Distance					
2.5	2.574	2.485	2.599	500 RPM at 2.5in	2.553
4	1.978	1.819	1.901	500 RPM at 4 in.	1.899
8	0.377	0.421	0.395	500 RPM at 8 in.	0.398
RPM	750				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	2.112	2.101	2.044	750 RPM at 2.5in	2.086
4	1.241	1.233	1.152	750 RPM at 4 in.	1.209
8	0.201	0.208	0.205	750 RPM at 8 in.	0.205
RPM	1000				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	1.616	1.44	1.403	1000 RPM at 2.5 in.	1.486
4	0.839	0.894	0.881	1000 RPM at 4 in.	0.871
8	0.157	0.13	0.143	1000 RPM at 8 in.	0.143

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Test Process

Biobased 3 Winter Grease

Date: 12-Jul-13

Operator: Darren Keppy

Grease Quantity: 2 grams +/- .6 grams

Time 20 sec.

RPM	500				
	Trial 1	Trial 2	Trial 3		Averages
Distance					
2.5	2.453	2.483	2.331	500 RPM at 2.5in	2.422
4	1.685	1.659	1.766	500 RPM at 4 in.	1.703
8	0.43	0.423	0.384	500 RPM at 8 in.	0.412
RPM	750				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	1.827	1.876	1.769	750 RPM at 2.5in	1.824
4	0.964	1.157	1.162	750 RPM at 4 in.	1.094
8	0.199	0.221	0.208	750 RPM at 8 in.	0.209
RPM	1000				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	1.272	1.339	1.346	1000 RPM at 2.5 in.	1.319
4	0.864	0.858	0.865	1000 RPM at 4 in.	0.862
8	0.147	0.14	0.137	1000 RPM at 8 in.	0.141

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Test Process

Biobased 3 Summer Grease

Date: 29 August 2013

Operator: Darren

Grease Quantity: 2 grams +/- .6 grams

Time 10 sec.

RPM	500				
	Trial 1	Trial 2	Trial 3		Averages
Distance					
2.5	2.798	2.742	2.735	500 RPM at 2.5in	2.758
4	2.498	2.209	2.064	500 RPM at 4 in.	2.257
8	0.577	0.566	0.549	500 RPM at 8 in.	0.564
RPM	750				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	2.506	2.498	2.552	750 RPM at 2.5in	2.519
4	1.517	1.407	1.549	750 RPM at 4 in.	1.491
8	0.256	0.248	0.24	750 RPM at 8 in.	0.248
RPM	1000				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	1.7	1.785	1.694	1000 RPM at 2.5 in.	1.726
4	1.009	0.981	0.956	1000 RPM at 4 in.	0.982
8	0.184	0.166	0.171	1000 RPM at 8 in.	0.174

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Test Process

Biobased 3 Summer Grease

Date: 29 August 2013

Operator: Darren

Grease Quantity: 2 grams +/- .6 grams

Time 20 sec.

RPM	500				
	Trial 1	Trial 2	Trial 3		Averages
Distance					
2.5	2.733	2.529	2.768	500 RPM at 2.5in	2.677
4	2.439	1.704	1.844	500 RPM at 4 in.	1.996
8	0.409	0.502	0.446	500 RPM at 8 in.	0.452
RPM	750				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	2.247	2.141	1.947	750 RPM at 2.5in	2.112
4	1.299	1.376	1.103	750 RPM at 4 in.	1.259
8	0.219	0.228	0.236	750 RPM at 8 in.	0.228
RPM	1000				
	Trial 1	Trial 2	Trial 3		
Distance					
2.5	1.475	1.578	1.562	1000 RPM at 2.5 in.	1.538
4	0.912	0.935	0.926	1000 RPM at 4 in.	0.924
8	0.151	0.139	0.134	1000 RPM at 8 in.	0.141

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Abbreviations and Acronyms

American Chemical Society	ACS
European Association for the Coordination of Consumer Representation in Standardization	ANEC
American National Standards Institute	ANSI
American Petroleum Institute	API
American Society for Testing and Materials	ASTM
European Committee for Standardization	CEN
European Lubricating Grease Institute	ELGI
Environmental Protection Agency	EPA
Federal Railroad Administration	FRA
International Energy Agency	IEA
International Organization for Standards	ISO
National Institute of Standards and Technology	NIST
National Lubricating Grease Institute	NLGI
National Sanitation Foundation	NSF
Organization for Economic Co-operation and Development	OECD
Society of Automotive Engineers	SAE
U.S. Department of Agriculture	USDA